Freescale Semiconductor, Inc.
Data Sheet: Technical Data

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MKW01Z128

Package Information

MKW01Z128

Highly-integrated, cost-effective single-package solution for sub-1 GHz applications

Ordering Information

Device	Device Marking	Package
MKW01Z128CHN	MKW01Z128CHN	60 LGA

1 Introduction

The MKW01 device is highly-integrated, cost-effective, smart radio, sub-1 GHz wireless node solution composed of a transceiver supporting FSK, GFSK, MSK, or OOK modulations with a low-power ARM® Cortex M0+ CPU. The highly integrated RF transceiver operates over a wide frequency range including 315 MHz, 433 MHz, 470 MHz, 868 MHz, 915 MHz, 928 MHz, and 955 MHz in the license-free Industrial, Scientific and Medical (ISM) frequency bands. This configuration allows users to minimize the use of external components.

The MKW01 is targeted for the following low-power wireless applications:

- Automated Meter Reading
- Wireless Sensor Networks
- Home and Building Automation
- Wireless Alarm and Security Systems
- Industrial Monitoring and Control

Freescale supplements the MKW01 with tools and software that include hardware evaluation and

development boards, software development IDE and applications, drivers, custom PHY usable with Freescale's IEEE 802.15.4 compatible MAC and SMAC.

2 Features

This section provides a simplified block diagram and highlights MKW01 features.

2.1 Block Diagram

Figure 1 shows a simplified block diagram of the MKW01.

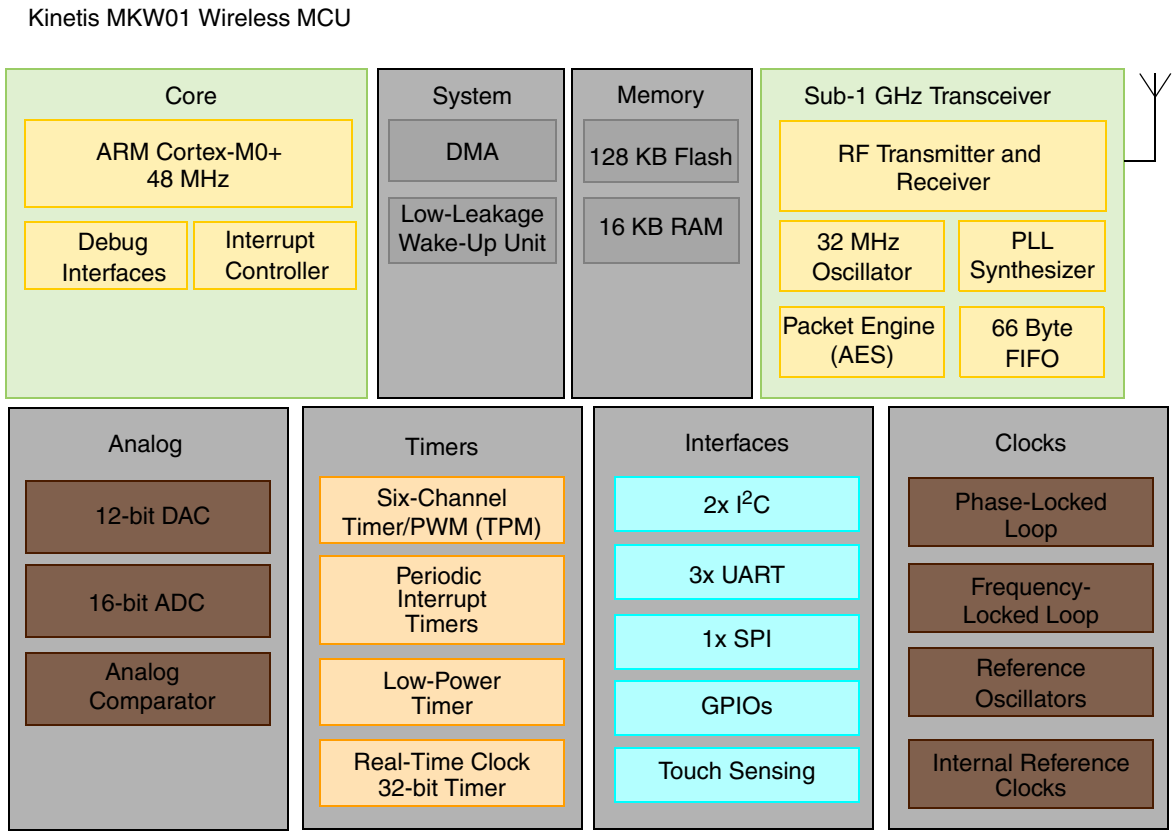


Figure 1. MKW01 Simplified Block Diagram

2.2 Features Summary

- **RF Transceiver Features**
  - — Operating Voltage from 1.8V to 3.6V.
  - — Programmable bit rate up to 600kbps (FSK)
  - — High Sensitivity: down to -120 dBm at 1.2 kbps
  - — High Selectivity: 16-tap FIR Channel Filter

- Bullet-proof front end: IIP3 = -18 dBm, IIP2 = +35 dBm, 80 dB Blocking Immunity, no Image Frequency response
- Low current: Rx = 16mA, 100nA register retention
- Programmable Pout : -18 to +17 dBm in 1 dB steps
- Constant RF performance over voltage range of chip
- Fully integrated synthesizer with a resolution of 61 Hz
- FSK, GFSK, MSK, GMSK and OOK modulations
- Built-in Bit Synchronizer performing Clock recovery
- Incoming Sync Word Recognition
- Automatic RF Sense with ultra-fast AFC
- Packet engine with CRC, AES-128 encryption and 66-byte FIFO
- Built-in temperature sensor and Low battery indicator
- 32 MHz crystal oscillator clock source
- Dedicated I/O's for connection with an external 32 kHz crystal
- Can be configured to be compliant with the relevant sections of numerous world-wide standards, including but not limited to: ARIB-T108 and T67, FCC 15.231, 15.247, and 15.249, EN54-25, and ETSI 300 220.

- **MCU Features**

System**:**

- 48 MHz Max. Central Processor Unit (CPU) frequency
- 24 MHz Max. Bus frequency
- Vectored Interrupt Controller (NVIC) with 32 core-vectored interrupts with 4 programmable interrupt priority levels
- Asynchronous Wake-up Interrupt Controller (AWIC)
- 4 channel Direct Memory Access (DMA)
- DMA request multiplex
- Non Maskable Interrupt (NMI)
- COP Watchdog
- Low leakage Wake-up Unit (LLWU)
- Debug and Trace
  - 2-pin Serial Wire Debug (SWD)
- 80-bit wide ID number

Memory**:**

- 128 KB P-Flash with 64 byte flash cache
- 16 KB RAM

Clocks:

- External crystal oscillator or resonator:

- 32 - 40 kHz low range, low power or full swing
- 3 MHz - 32 MHz high range, low power or full swing

— DC - 48 MHz external square wave input clock

— Internal clock references:
- 31.25 kHz to 39.063 kHz oscillator with +/– 1.5% max. deviation from 0 to +70°C
- 4 MHz oscillator with +/– 3% max. deviation across temperature
- 1 kHz oscillator

— Phase Locked Loop (PLL) with up to 100 MHz VCO

— Frequency Locked Loop (FLL):
- Low range: 20 - 25 MHz
- Mid range: 40 - 48 MHz

Analog:

— Power Management Controller (PMC) with low voltage warning (LVW) and detect with selectable trip points.

— 16-bit analog to digital converter
- 11 single ended channels available
- 2 status, control and results registers
- DMA support

— 1 High Speed Comparator (HSCMP) with internal 6-bit digital to analog converters (DAC)

— One 12-bit DAC with DMA support and 2 word data buffer

Timers:

— Six channel Timer/PWM (TPM)

— Periodic interrupt timers

— 16-bit low-power timer (LPTMR) can be configured to operate as a time counter or as a pulse counter, across all power modes, including the low-leakage modes

— Real-time clock 32-bit timer

Wired Communication Interface:

— One Serial Peripheral Interface (SPI) available externally

— Two Inter-Integrated Circuits (I^2C) with DMA support

— Three Universal Asynchronous Receiver / Transmitter (UART) with DMA Support
- UART0 supports standard features plus:
  - TxD pin can be configured as pseudo open drain for 1-wire half-duplex
  - x4 to x32 oversampling
  - Functional in VLPS mode
  - LIN slave operation

- UART1 and UART2 support standard features

Human Machine Interface (HMI)

— General Purpose Input/Output (GPIO) supporting:
  - Default to disabled (no leakage)
  - 4 pins with 18 mA high current drive capability
  - Hysteresis and configurable pull up device on all input pins
  - Slew rate and drive strength fixed on all output pins
  - Single cycle GPIO control via IOPORT

— Touch Sensor Inputs (TSI)
  - 9-channel
  - Selectable single channel wakeup source available in all modes
  - DMA support

— Pin Interrupt

1.8 V to 3.6 V operating voltage with on-chip voltage regulators

Temperature range of –40°C to 85°C

60-pin LGA (8x8 mm) package

3 Software Solutions

Freescale will support the MKW01x128 platform with several software solutions:

- A radio utility GUI will be available that allows testing of various features and setting registers. A connectivity test firmware will allow a limited set of testing controlled with a terminal emulator on any computer.
- SMAC (Simple Media Access Controller) — This codebase provides simple communication and test apps based on drivers/PHY utilities available as source code. This environment is useful for hardware and RF debug, hardware standards certification, and developing proprietary applications.
- Additional software will be available through 3rd party providers.

4 Smart Radio Sub-1 GHz Wireless Node

The MKW01 brings together a transceiver chip and an MCU chip on a single substrate to provide a small footprint, cost-effective sub-1 GHz wireless node. The transceiver is controlled by the MCU through a dedicated SPI interface. The SPI bus interface and some status signals are connected in-package the substrate to eliminate the need for external connections. The SPI supports bit order swapping providing hardware support for bit endianess reducing processing overhead.

4.1 RF Transceiver

The transceiver (see Figure 2) is a single-chip integrated circuit ideally suited for today's high performance ISM band RF applications. Its advanced features set, including state of the art packet engine, greatly

simplifies system design while the high level of integration reduces the external RF component bill of material (BOM) to a handful of passive de-coupling and matching components. It is intended for use as a high-performance, low-cost FSK, GFSK, MSK, GMSK, and OOK RF transceiver for robust, frequency agile, half-duplex bi-directional RF links.

The MKW01 is intended for applications over a wide frequency range, including the 433 MHz, the 868 MHz European, and the 902-928 MHz North American ISM bands. Coupled with a link budget in excess of 135 dB, the transceiver advanced system features include a 66 byte TX/RX FIFO, configurable automatic packet handler, listen mode, temperature sensor and configurable DIO's which greatly enhance system flexibility while at the same time significantly reducing MCU requirements. The transceiver complies with both ETSI and FCC regulatory requirements.

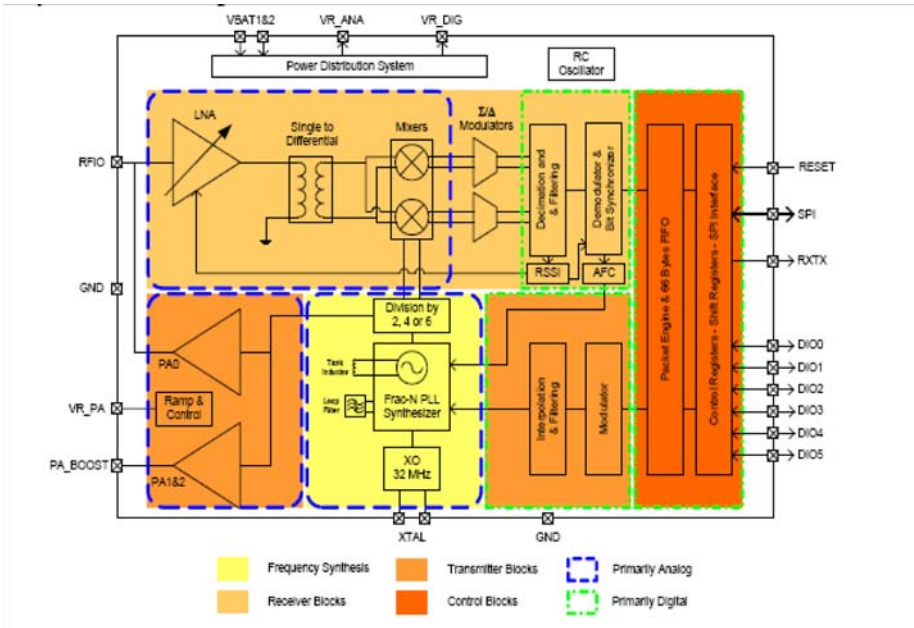


Figure 2. MKW01 Transceiver Block Diagram

The major RF communication parameters of the MKW01 transceiver are programmable and most can be dynamically set. This feature offers the unique advantage of programmable narrow-band and wide-band communication modes without the need to modify external components. The transceiver is also optimized for low power consumption while offering high RF output power and channelized operation.

4.2 ARM ® 32-bit Cortex M0+ CPU

The in-package MCU integrated circuit features an ARM ® Cortex M0+ CPU, up to 16 KB RAM, 128 KB Flash memory, and a rich set of peripherals (see Section 2.2, "Features Summary"). The RF transceiver is controlled through the MCU SPI port which is dedicated to the RF device interface. Two of the transceiver status IO lines are also directly connected to the MCU GPIO to monitor the transceiver operation. In addition, the transceiver reset and additional status can be connected to the MCU through external connections.

Operational modes of the MKW01 are determined by the software running on the MCU. The MCU itself has a run mode as well as an array of low power modes that are coordinated by the PMC. The MCU in turn set the operational modes of the transceiver which include sleep, standby, and radio operational modes.

Two common application scenarios are:

- Low power, battery-operated standalone wireless node - a common example of this configuration would be a remote sensor monitor. The wireless node programmed for standalone operation, typically has a low active-mode duty cycle, and is designed for long battery life, i.e., lowest power.
- Communication channel to a higher level controller - in this example, the wireless node implements the lower levels of a communications stack and is subordinate to the primary controller. Typically the MKW01 is connected to the controller through a command channel implemented via a UART/SCI port or other serial communication port.

4.3 System Clock Configuration

The MKW01 device allows for various system clock configurations:

- Pins 46 & 47 are provided to input a 32 or 30 MHz crystal for the transceiver reference clock source (required) as shown in Figure 3.
- The transceiver can be programmed to provide a programmable frequency clock output (DIO5 which alternates as CLKOUT, pin 54) that can be used as an external source to the CPU (see Figure 3 and Figure 4). As a result, a single crystal system clock solution is possible where the transceiver reference clock source. Routing CLKOUT to the MCU without dividing it is recommended, but it can be divided by 2, 4, 8, 16 and 32.
- The MCU provides a trimmable internal reference clock and also supports an external clock source. An optional on-chip frequency locked loop (FLL) can be used with either clock source to support a CPU clock as high as 48 MHz at 3.6 V.
- Pins 16 and 15 are available to provide an external 32.768 kHz external clock source for the MCU.

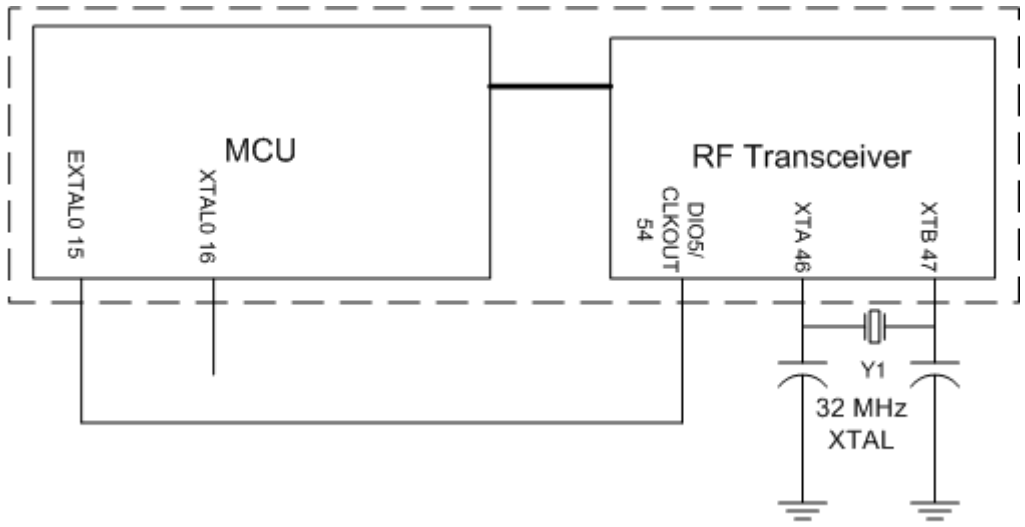


Figure 3. MKW01 Single Crystal System Clock Connection

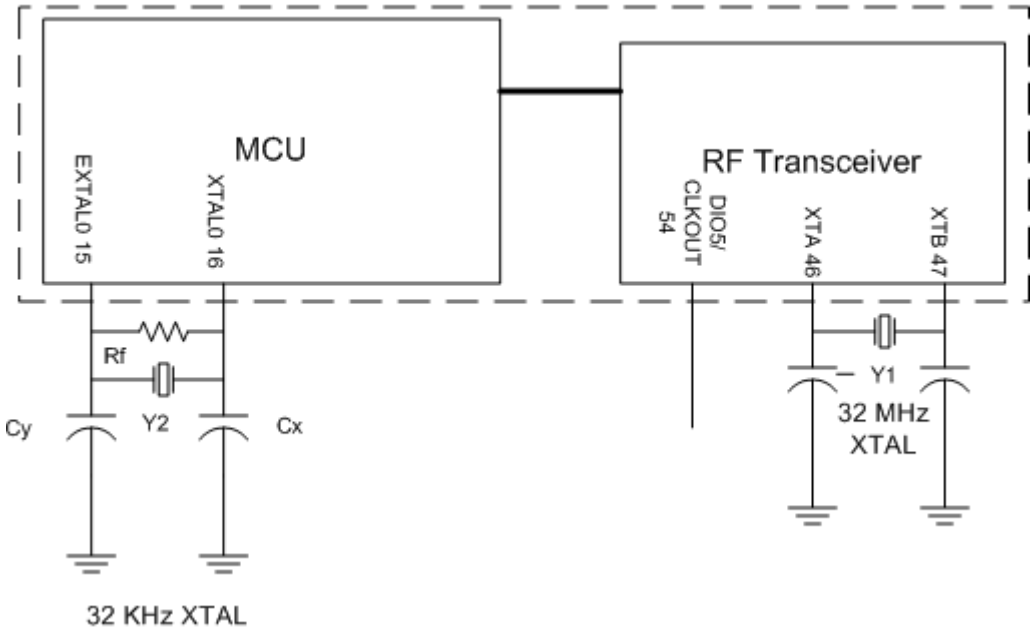
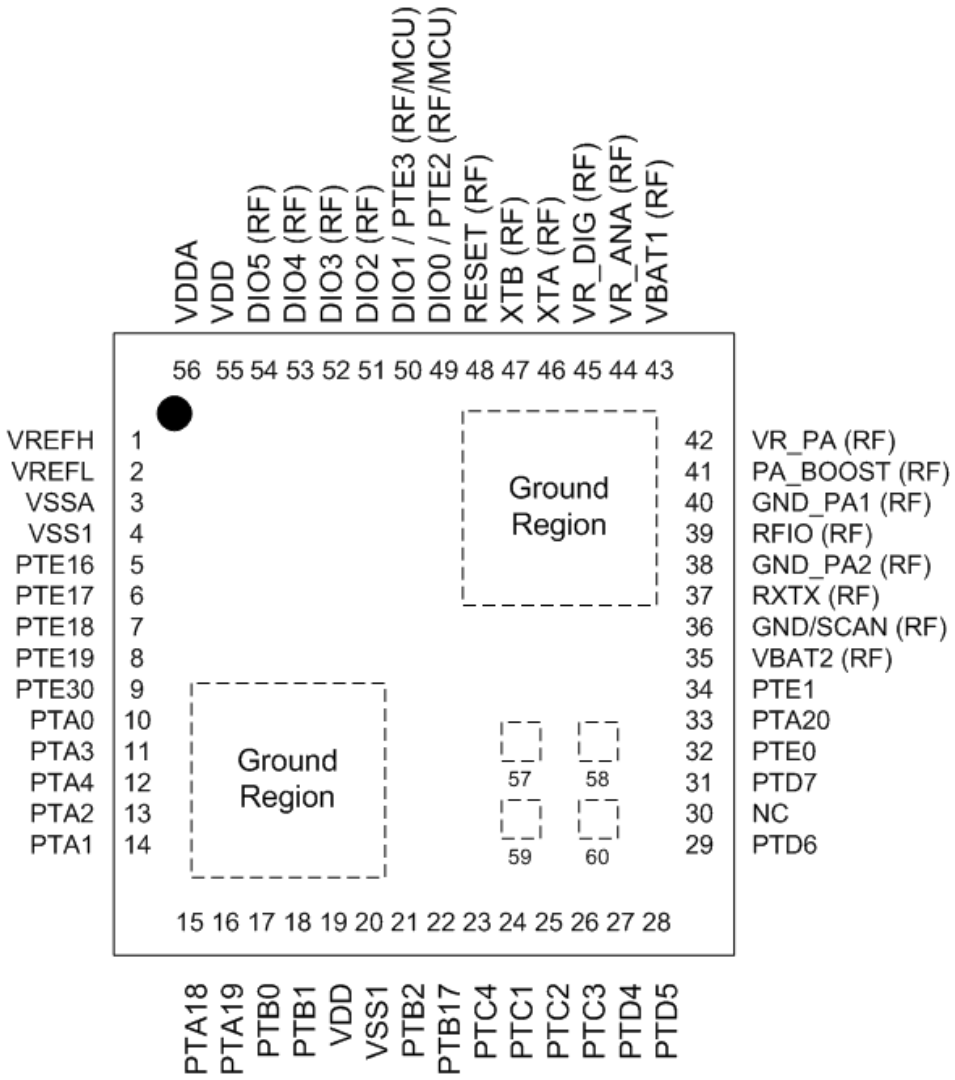


Figure 4. MKW01 Two Crystal System Clock Connection

5 MKW01 Pin Assignments and Connections

Figure 5 shows the MKW01 pinout.



2 ground regions and 4 pins on bottom:

57 MISO / PTC7 (RF/MCU)
58 NSS / PTD0 (RF/MCU)
59 SCK / PTC5 (RF/MCU)
60 MOSI / PTC6 (RF/MCU)

Figure 5. MKW01 Pinout (Top View)

5.1 Pin Definitions

Table 1 details the MKW01 pinout and functionality.

Table 1. Pin Function Description (Sheet 1 of 5)

Pin	Pin Name[1]	Type	Description	Functionality
1	VREFH	Input	MCU high reference voltage for ADC	
2	VREFL	Input	MCU low reference voltage for ADC	
3	VSSA	Power Input	MCU ADC Ground	Connect to ground
4	VSS	Power Input	MCU Ground	Connect to ground
5	PTE16/ADC0_DP1/ADCO_SE1/SPI0_PCS0/TPM/UART2_TX	Digital Input / Output	MCU Port E Bit 16 / ADC0 Single Ended analog channel input DP1/ ADC0 Single Ended analog channel input SE1 / SPI module 0 PCS0 / TPM module Clock In 0 / UART2_TX	
6	PTE17/ADC0_DM1/ADCO_SE5a/SPI0_SCK/ TPM_CLKIN1/UART2_RX/ LPTMR0_ALT3	Digital Input / Output	MCU Port E Bit 17 / ADC0 Single Ended analog channel input DM1/ ADC0 Single Ended analog channel input 5a / SPI module 0 SCK / TPM module Clock In 1 / UART2_RX / Low Power Timer Module 0 ALT3	
7	PTE18/ADC0_DP2/ADC0_SE2/SPI0_MOSI/IIC0_SDA/SPI0_MISO	Digital Input / Output	MCU Port E Bit 18 / ADC0 Single Ended analog channel input DP2/ ADC0 Single Ended analog channel input 2 / SPI module 0 MOSI / IIC0 Bus Data / SPI module 0 MISO	
8	PTE19/ADC0_DM2/ ADC0_SE6a/SPI0_MISO /IIC0_SCL/ SPI0_MOSI	Digital Input / Output	MCU Port E Bit 19 / ADC0 Single Ended analog channel input DM2/ ADC0 Single Ended analog channel input 6a / SPI module 0 MISO / IIC0 Bus Clock / SPI module 0 MOSI	
9	PTE30/DAC0_OUT/ ADCO_SE23/ CMP0_IN4/TPM0_CH3/TPM_CLKIN1	Digit-l Input / Output	MCU Port E Bit 30 / DAC0 Output/ ADC0 Single Ended analog channel input 23 / Comparator 0 Analog Voltage Input 4/ TPM Timer module 0 Channel 3 / TPM module Clock In 1	
10	PTA0/SWD_CLK/TSI0_CH1/TPM0_CH5	Digital Input / Output	MCU Port A Bit 0 / Serial Wire Data Clock / Touch Screen Interface Channel 1/ TPM module 0 Channel 5	
11	PTA3/SWD_DIO/TSI0_CH4/ IIC1_SCL/TPM0_CH0	Digital Input / Output	MCU Port A Bit 3 / Serial Wire Data DIO / Touch Screen Interface Channel 4 / IIC1 Bus Clock / TPM module 0 Channel 0	
12	PTA4/NMI_b/TSI0_CH5/ IIC1_SDA/TPM0_CH1	Digital Input / Output	MCU Port A Bit 4/ / Non Maskable Interrupt_ b/Touch Screen Interface Channel 5 /IIC1 Bus Data / TPM module 0 Channel 1	

Table 1. Pin Function Description (Sheet 2 of 5)

Pin	Pin Name[1]	Type	Description	Functionality
13	PTA2/TSI0_CH3/UART0_TX/ TPM2_CH1	Digital Input / Output	MCU Port A Bit 2/Touch Screen Interface Channel 3/UART module 0 Transmit / TPM module 2 Channel 1	
14	PTA1/TSI0_CH2/UART0_RX/ TPM2_CH0	Digital Input / Output	MCU Port A Bit 1/Touch Screen Interface Channel 2/UART module 0 Receive / TPM module Channel 0	
15	PTA18/EXTAL0/UART1_RX/ TPM_CLKIN0	Digital Input / Output	MCU Port A Bit 18 / EXTAL0/ UART module 1 Receive / TPM module Clock In 0	
16	PTA19/XTAL0/UART1_TX/TPM_CLKIN1/LPTMR0_ALT1	Digital Input / Output	MCU Port A Bit 19 / XTAL0/ UART module 1 Transmit / TPM module Clock In 1 /Low Power Timer module 0 ALT1	
17	PTB0/ADC0_SE8/TSI0_CH0/ LLWU_P5/IIC0_SCL/ TPM1_CH0	Digital Input / Output	MCU Port B Bit 0 / ADC0 Single Ended analog channel input SE8 / Touch Screen Interface Channel 0/ Low Leakage Wake Up Port 5 / IIC0 Bus Clock / TPM module 1 Channel 0	
18	PTB1/ADCO_SE9/TSI0_CH6/ IIC0_SDA/ TPM1_CH1	Digital Input / Output	MCU Port B Bit 1 / ADC0 Single Ended analog channel input SE9 / Touch Screen Interface Channel 6 / IIC0 Bus Data / TPM module 1 Channel 1	
19	VDD	Power Input	MCU VDD supply input	Connect to system VDD supply
20	VSS	Power Input	MCU Ground	Connect to ground
21	PTB2/ADC0_SE12/TSI0_CH7 /IIC0_SCL/TPM2_CH0	Digital Input/Output	MCU Port B Bit 2 / ADC0 Single Ended analog channel input SE12 / Touch Screen Interface Channel 7 / IIC0 Bus Clock / TPM Timer module 2 Channel 0	
22	PTB17/TSI0_CH10/SPI1_MISO/UART0_TX/TPM_CLKIN1/ SPI1_MOSI	Digital Input/Output	MCU Port B Bit 17 / Touch Screen Interface Channel 10/SPI1 MOSI or MISO/UART0 TX / TPM timer clock	
23	PTC4/LLWU_P8/SPI0_PCS0/ UART1_TX/TPM0_CH3	Digital Input / Output	MCU Port C bit 4 / Low leakage Wake Up port 8 / SPI0 Chip Select / UART1 TX / TPM Timer module 0 channel 3	
24	PTC1/ADC0_SE15/TSI0_CH14/LLWU_P6/RTC_CLKIN/ IIC1_SCL/TPM0_CH0	Digital Input Output / Analog Input	MCU Port C Bit 1 /ADC0 Single Ended analog channel input SE15/ Touch Screen Interface Channel 14/ Low Leakage Wake Up Port 6 / Real Time Counter Clock Input/ IC1 Bus Clock/ TPM module 0 Channel 0	
25	PTC2/ADC0_SE11/TSI0_CH15/IIC1_SDA/TPM0_CH1	Digital Input / Output / Analog Input	MCU Port C Bit 2 / ADC0 Single Ended analog channel input SE11/ / Touch Screen Interface Channel 15 / IIC1 Bus Data / TPM module 0 Channel 1	

Table 1. Pin Function Description (Sheet 3 of 5)

Pin	Pin Name[1]	Type	Description	Functionality
26	PTC3/LLWU_P7/UART1_RX/ TPM0_CH2/CLKOUTa	Digital Input / Output	MCU Port C Bit 3 / Low Leakage Wake Up Port 7 / UART module 1 Receive / TPM module 0 Channel 2/ Clock OutA	
27	PTD4/LLWU_P14/SPI1_PCS0 /UART2_RX/TPM0_CH4	Digital Input / Output	MCU Port D Bit 4 / Low Leak Wake Up Port 14/ SPI module 1 PCS0 / UART2 Receiver input / TPM module 0 Channel 4	
28	PTD5/ADC0_SE6b/SPI1_SC K/UART2_TX/TPM0_CH5	Digital Input / Output / Analog Input	MCU Port D bit 5 / ADC0 Single Ended analog channel input SE6b / SPI1 clock / UART2 TX / TPM module 0 Channel 5	
29	PTD6/ADC0_SE7b/LLWU_P1 5/SPI1_MOSI/UART0_RX/SPI 1_MISO	Digital Input / Output / Analog Input	MCU Port D bit 6 / ADC0 Single Ended analog channel input SE7b / Low leakage Wake Up port 15 / SPI1 MOSI / UART0 RX / SPI module 1 MISO	
30	NC		No Connect	
31	PTD7/SPI0_MISO/UART0_TX /SPI1_MOSI	Digital Input/Output	MCU Port D Bit 7 / SPI module 0 MISO / UART module 0 Transmit / SPI module 1 MOSI	
32	PTE0/SPI1_MISO/UART1_TX /RTC_CLKOUT/CMP0_OUT/ IIC1_SDA	Digital Input/Output	MCU Port E Bit 0 / SPI module 1 MISO / UART module 1 Transmit / Real Time Counter Clock Output / Comparator 0 Analog voltage Output / IIC1 Bus Data	
33	PTA20/RESETB	Digital Input/Output	MCU Port A Bit 20/MCU $\overline{\text{RESET}}$	
34	PTE1 / SPI1_MOSI / UART1_RX /SPI1_MISO / IIC1_SCL	Digital Input/Output	MCU Port E Bit 1 / SPI module 1 MOSI / UART module 1 RX / SPI1_MISO / IIC1_SCL	
35	VBAT2 (RF)	Power Input	Transceiver VDD	Connect to system VDD supply
36	GND/SCAN (RF)	Power Input	Transceiver Ground	Connect to ground
37	RXTX (RF)	Digital Output	Transceiver Rx / Tx RF Switch Control Output; high when in TX	
38	GND_PA2 (RF)	Power Input	Transceiver RF Ground	Connect to ground
39	RFIO (RF)	RF Input / Output	Transceiver RF Input / Output	
40	GND_PA1 (RF)	Power Input	Transceiver RF Ground	Connect to ground
41	PA_BOOST (RF)	RF Output	Transceiver Optional High-Power PA Output	
42	VR_PA (RF)	Power Output	Transceiver regulated output voltage for VR_PA use.	De-coupling cap suggested.
43	VBAT1 (RF)	Power Input	Transceiver VDD for RF circuitry	Connect to system VDD supply

Table 1. Pin Function Description (Sheet 4 of 5)

Pin	Pin Name[1]	Type	Description	Functionality
44	VR_ANA (RF)	Power Output	Transceiver regulated output voltage for analog circuitry.	Decouple to ground with 100 nF capacitor
45	VR_DIG (RF)	Power Output	Transceiver regulated output voltage for digital circuitry.	Decouple to ground with 100 nF capacitor
46	XTA (RF)	Xtal Osc	Transceiver crystal reference oscillator	Connect to 32 MHz crystal and load capacitor
47	XTB (RF)	Xtal Osc	Transceiver crystal reference oscillator	Connect to 32 MHz crystal and load capacitor
48	RESET (RF)	Digital Input	Transceiver hardware reset input	Typically driven from MCU GPIO
49	DIO0/PTE2/SPI1_SCK	Digital Input/Output	Internally connected to Transceiver GPIO bit 0 and MCU Port E bit 2 / SPI1 clock	MCU IO and Transceiver IO connected in-package
50	DIO1/PTE3/SPI1_MISO/SPI1_MOSI	Digital Input/Output	Internally connected to Transceiver GPIO bit 1 and MCU Port E bit 3 /SPI1 in or out	MCU IO and Transceiver IO connected in-package
51	DIO2	Digital Input/Output	Transceiver GPIO Bit 2	
52	DIO3	Digital Input/Output	Transceiver GPIO Bit 3	
53	DIO4	Digital Input/Output	Transceiver GPIO Bit 4	
54	DIO5/CLKOUT	Digital Input/Output	Transceiver GPIO Bit 5 / ClkOut	Commonly programmed as ClkOut to supply MCU clock; connect to Pin 15
55	VDD	Power Input	MCU VDD supply	Connect to VDD supply
56	VDDAD	Power Input	MCU Analog supply	Connect to Analog supply
57	MISO/PTC7/SPI0_MISO/SPI0_MOSI	Digital Input/Output	Internal SPI data connection from Transceiver MISO bit 1 to MCU SPI0 (Port C bit 7)	• MCU IO and Transceiver IO connected in-package • MCU IO must be configured for this connection
58	NSS/PTD0/SPI0_PCS0	Digital Input/Output	Internal SPI select connection between Transceiver NSS and MCU SPI0 (Port D bit 0)	• MCU IO and Transceiver IO connected in-package • MCU IO must be configured for this connection
59	SCK/PTC5/SPI0_SCK	Digital Input/Output	Internal SPI clock connection between Transceiver SCK and MCU SPI0 (port C bit 5)	• MCU IO and Transceiver IO connected in-package • MCU IO must be configured for this connection

Table 1. Pin Function Description (Sheet 5 of 5)

Pin	Pin Name[1]	Type	Description	Functionality
60	MOSI/PTC6/SPI0_MOSI/ SPI0_MISO	Digital Input/Output	Internal SPI data connection to Transceiver MOSI bit 1 to MCU SPI0 (Port C bit 6)	• MCU IO and Transceiver IO connected in-package • MCU IO must be configured for this connection
FLAG	VSS	Power input	External package flag. Common VSS	Connect to ground.

1 Refer to ADD Table 1-3 for additional pin-out information on default and alternate setting selections.

5.2 Internal Functional Interconnects

The MCU provides control to the transceiver through the SPI Port and receives status from the transceiver from the DIOx pins. Certain interconnects between the devices are routed on chip. In addition, the signals are brought out to external pads.

Table 2. MKW01 Internal Functional Interconnects

Pin	MCU Signal	Transceiver Signal	Description
49	DIO0/PTE2/SPI1_ SCK	DIO0	Transceiver DIO0 can be programmed to provide status to the MCU
50	DIO1/PTE3/SPI1_ MISO/SPI1_MOSI	DIO1	Transceiver DIO1 can be programmed to provide status to the MCU
57	MISO/PTC7/SPI0_ MISO/SPI0_MOSI	MISO	SPI data from transceiver to MCU
58	NSS/PTD0/SPI0_ PCS0	NSS	SPI chip select
59	SCK/PTC5/SPI0_ SCK	SCK	SPI Clock
60	MOSI/PTC6/SPI0_ MOSI/SPI0_MISO	MOSI	SPI data from MCU to transceiver

NOTE

- As shown in Table 2, the MCU SPI Port pin selection must be configured by software.
- The transceiver DIO pins must be programmed to provide desired status.
- Enhanced performance can be achieved by additionally routing some DIO pins externally to other GPIO pins.

5.3 External Functional Interconnects

In addition to the in-package device interconnection, other external connections between the MCU and the transceiver are common:

1. Freescale recommends driving/controlling the transceiver reset from an MCU GPIO - This allows overriding control of the transceiver from the system application.
2. The other DIO2-DIO4 status and RXTX signals can prove useful for monitoring the transceiver operation - the DIO2-DIO4 signals must be programmed to provide operational status. All signals must be connected externally to appropriate MCU GPIO for this function.

6 System and Power Management

The MKW01 consists of an independent transceiver and MCU. The MCU controls the transceiver through programming of the SPI Port, and sets its operational mode through this control channel. Total current draw for the MKW01 is dependent on the operation mode of both devices where different modes allow for different levels of power-down. Some additional features supported are:

- Transceiver Sleep with MCU set at the lowest power state.
- The transceiver mode selection being independent of the MCU's mode selection.
- The transceiver uses/powers-up the transmitter or receiver only as required.
- MCU peripheral control clock gating being disabled on a module-by-module basis to provide lowest power.
- RTC can be used as wake-up timer.
- LLWU (Low Leakage Wake-up Unit) available.

6.1 MCU Power Modes

The MCU has 9 different modes of operation to allow the user to optimize power consumption for the level of functionality needed. Depending on the STOP requirements of the user application, a variety of STOP modes are available that provide state retention, partial power down or full power down of certain logic and/or memory. I/O states are held in all modes of operation. Table 3 outlines the various available power modes of MCU operation.

For each RUN mode there is a corresponding WAIT and STOP mode. WAIT modes are similiar to ARM sleep modes. STOP modes (VLPS, STOP) are similiar to ARM sleep deep mode. The very low power run (VLPR) operating mode can greatly reduce runtime power when the maximum bus frequency is not required to handle application needs. The 3 primary modes of operation are RUN, WAIT and STOP. The WFI instruction invokes both WAIT and STOP modes for the MCU. The primary modes are augmented in a number of ways to provide lower power based on application needs.

Table 3. MCU power modes

Chip Power Mode	Description	Core Mode	Normal Recovery Method
Normal run	Allows maximum performance of chip. Default mode out of reset; onchip voltage regulator is on.	Run	—
Normal Wait - via WFI	Allows peripherals to function while the core is in sleep mode, reducing power. NVIC remains sensitive to interrupts; peripherals continue to be clocked.	Sleep	Interrupt
Normal Stop - via WFI	Places chip in static state. Lowest power mode that retains all registers while maintaining LVD protection. NVIC is disabled; AWIC is used to wake up from interrupt; peripheral clocks are stopped.	Sleep Deep	Interrupt
VLPR (Very Low Power Run)	On-chip voltage regulator is in a low power mode that supplies only enough power to run the chip at a reduced frequency. Reduced frequency Flash access mode (1 MHz); LVD off; in BLPI clock mode, the fast internal reference oscillator is available to provide a low power nominal 4 MHz source for the core with the nominal bus and flash clock required to be <800 kHz; alternatively, BLPE clock mode can be used with an external clock or the crystal oscillator providing the clock source.	Run	—
VLPW (Very Low Power Wait) -via WFI	Same as VLPR but with the core in sleep mode to further reduce power; NVIC remains sensitive to interrupts (FCLK = ON). On-chip voltage regulator is in a low power mode that supplies only enough power to run the chip at a reduced frequency.	Sleep	Interrupt
VLPS (Very Low Power Stop)-via WFI	Places chip in static state with LVD operation off. Lowest power mode with ADC and pin interrupts functional. Peripheral clocks are stopped, but OSC, LPTMR, RTC, CMP, TSI can be used. TPM and UART can optionally be enabled if their clock source is enabled. NVIC is disabled (FCLK = OFF); AWIC is used to wake up from interrupt. On-chip voltage regulator is in a low power mode that supplies only enough power to run the chip at a reduced frequency. All SRAM is operating (content retained and I/O states held).	Sleep Deep	Interrupt
LLS (Low Leakage Stop)	State retention power mode. Most peripherals are in state retention mode (with clocks stopped), but OSC, LLWU, LPTMR, RTC, CMP,, TSI can be used. NVIC is disabled; LLWU is used to wake up. **NOTE:** The LLWU interrupt must not be masked by the interrupt controller to avoid a scenario where the system does not fully exit stop mode on an LLS recovery. All SRAM is operating (content retained and I/O states held).	Sleep Deep	Wakeup Interrupt[1]

Table 3. MCU power modes

Chip Power Mode	Description	Core Mode	Normal Recovery Method
VLLS3 (Very Low Leakage Stop3)	Most peripherals are disabled (with clocks stopped), but OSC, LLWU, LPTMR, RTC, CMP, TSI can be used. NVIC is disabled; LLWU is used to wake up. SRAM_U and SRAM_L remain powered on (content retained and I/O states held).	Sleep Deep	Wakeup Reset[2]
VLLS1 (Very Low Leakage Stop1)	Most peripherals are disabled (with clocks stopped), but OSC, LLWU, LPTMR, RTC, CMP, TSI can be used. NVIC is disabled; LLWU is used to wake up. All of SRAM_U and SRAM_L are powered off.	Sleep Deep	Wakeup Reset[2]
VLLS0 (Very Low Leakage Stop 0)	Most peripherals are disabled (with clocks stopped), but LLWU, LPTMR, RTC, TSI can be used. NVIC is disabled; LLWU is used to wake up. All of SRAM_U and SRAM_L are powered off. LPO disabled, optional POR brown-out detection	Sleep Deep	Wakeup Reset[2]

1 Resumes normal run mode operation by executing the LLWU interrupt service routine.

2 Follows the reset flow with the LLWU interrupt flag set for the NVIC.

6.1.1 Power mode transitions

Figure 6 shows power mode transitions. Any reset always brings the MCU back to normal state run. In RUN, WAIT and STOP modes active power regulation is enabled. The VLPx modes are limited in frequency but offer a lower power operating power mode than normal modes. The LLS and VLLSx modes are the lowest power stop modes based on the amount of logic or memory that is required to be reatined by the application.

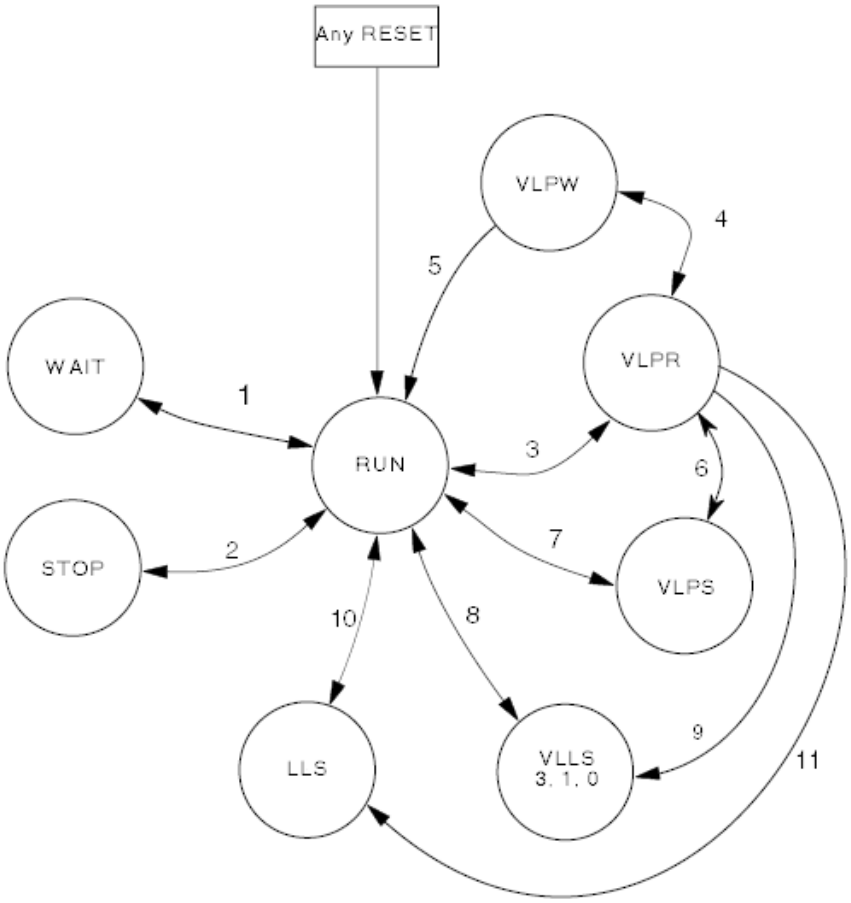


Figure 6. Power mode state transition diagram

6.2 Transceiver modes of operation.

The transceiver can be set in numerous modes of operation as described in Table 4. By default, when switching from one mode to another various features are selectively turned on coordinated by a pre-defined optimized sequence using the automatic sequencer. Alternatively, these operating modes can be selected directly by disabling the automatic sequencer.

Table 4. Basic Transceiver modes

Selected Mode	Enabled blocks
Sleep	None
Stand-by	Main regulator and crystal oscillator
Idle	Main regulator and RC oscillator
FS	Frequency synthesizer
Transmit	Frequency synthesizer and transmitter
Receive	Frequency synthesizer and receiver
Listen	Periodical receive wake-up from Idle operation

An overview of the transceiver modes of operation is described below:

- Sleep - provides lowest power consumption and is the full power down state.
- Idle - provides very low standby power consumption and has the main voltage regulator and the RC oscillator enabled.
- Standby - similar to Idle with low standby power consumption but has the main voltage regulator and the crystal oscillator enabled.
- FS (Frequency synthesizer) - the frequency synthesizer is alive to shorten startup time to transmit or receive states.
- Transmit - transmitter is active.
- Receive - receiver is active.

6.3 System Protection

The MKW01 provides numerous vehicles to maintain security or a high level of system robustness:

- Standard COP Watchdog reset with option to run from dedicated 1 kHz internal clock source or bus clock. The COP watchdog is intended to force a system reset when the application software fails to execute as expected.
- LVD protection with reset or interrupt; selectable trip points.
- HardFault exception on attempts to execute undefined instructions or access to undefined memory space.
- LOCKUP reset resource from core.
- Flash protection

7 Development Environment

Development support for the ARM® Cortex M0+ MCU on the MKW01 is configured to provide maximum flexibility as allowed by the restrictions of the pinout and other available resources. One debug interface is supported:

• Two-wire Serial Wire Debug (SWD) interface

Table 5 presents a brief description of the serial wire debug description.

NOTE

Electrical specifications for the SWD lines can be found in the appendix.

Table 5. Debug Components Description

Module	Type	Description
SWCLK	Input	Serial Wire Clock. This pin is the clock for debug logic when in the Serial Wire Debug mode. This pin is pulled down internally.
SWDIO	Input /Output	Serial Wire debug data input / output. The SWDIO pin is used by an external debug tool for communication and devive control. This pin is pulled up internally.

8 System Electrical Specification

This section details maximum ratings for the 60-pin LGA package and recommended operating conditions, DC characteristics, and AC characteristics for the modem, and the MCU.

8.1 LGA Package Maximum Ratings

Absolute maximum ratings are stress ratings only, and functional operation at the maximum rating is not guaranteed. Stress beyond the limits specified in Table 6 may affect device reliability or cause permanent damage to the device. For functional operating conditions, refer to the remaining tables in this section.

This device contains circuitry protecting against damage due to high static voltage or electrical fields; however, it is advised that normal precautions be taken to avoid application of any voltages higher than maximum-rated voltages to this high-impedance circuit. Reliability of operation is enhanced if unused inputs are tied to an appropriate logic voltage level (for instance, either V_{SS} or V_{DD}) or the programmable pull-up resistor associated with the pin is enabled.

Table 6 shows the maximum ratings for the 60-pin LGA package.

Table 6. LGA Package Maximum Ratings

Rating	Symbol	Value	Unit
Maximum Junction Temperature	T_J	95	°C
Storage Temperature Range	T_{stg}	-55 to 115	°C
Power Supply Voltage	V_{BATT}, V_{DDINT}	-0.3 to 3.8	Vdc
Digital Input Voltage	Vin	-0.3 to (V_{DDINT} + 0.3)	
RF Input Power	P_{max}	6	dBm

Note: Maximum Ratings are those values beyond which damage to the device may occur. Functional operation should be restricted to the limits in the Electrical Characteristics or Recommended Operating Conditions tables.

Note: Meets Human Body Model (HBM) = 2 kV. RF input/output pins have no ESD protection.

8.2 ESD Protection and Latch-Up Immunity

Although damage from electrostatic discharge (ESD) is much less common on these devices than on early CMOS circuits, normal handling precautions should be used to avoid exposure to static discharge. Qualification tests are performed to ensure that these devices can withstand exposure to reasonable levels of static without suffering any permanent damage.

All ESD testing is in conformity with the JESD22 Stress Test Qualification for Commercial Grade Integrated Circuits. During the device qualification ESD stresses were performed for the human body model (HBM), the machine model (MM) and the charge device model (CDM).

All latchup testing is in conformity with the JESD78 IC Latch-Up Test.

A device is defined as a failure if after exposure to ESD pulses the device no longer meets the device specification.

Table 7. ESD and Latch-up Test Conditions

Model	Description	Symbol	Value	Unit
Human Body	Series resistance	R1	1500	Ω
	Storage capacitance	C	100	pF
	Number of pulses per pin[1]	—	1	
Machine	Series resistance	R1	0	Ω
	Storage capacitance	C	200	pF
	Number of pulses per pin[1]	—	1	
Latch-up	Minimum input voltage limit		– 1.8	V
	Maximum input voltage limit		4.32	V

1 This number represents a minimum number for both positive pulse(s) and negative pulse(s)

Table 8. ESD and Latch-Up Protection Characteristics

No.	Rating[1]	Symbol	Min	Max	Unit
1	Human body model (HBM)	V_{HBM}	± 2000	—	V
2	Machine model (MM)	V_{MM}	± 200	—	V
3	Charge device model (CDM)	V_{CDM}	± 500	—	V
4	Latch-up current at T_A = 85°C	I_{LAT}	± 100	—	mA

1 Parameter is achieved by design characterization on a small sample size from typical devices under typical conditions unless otherwise noted.

8.3 Transceiver Electrical Characteristics

The tables below give the electrical specifications of the transceiver under the following conditions: Supply voltage VBAT1= VBAT2=VDD=3.3 V, temperature = 25 °C, FXOSC = 32 MHz, FRF = 915 MHz, Pout = +13dBm, 2-level FSK modulation without pre-filtering, FDA = 5 kHz, Bit Rate = 4.8 kb/s and terminated in a matched 50 Ohm impedance, unless otherwise specified.

NOTE

Unless otherwise specified, the performances in the other frequency bands are similar or better.

8.3.1 Transceiver Recommended Operating Conditions

Table 9. Recommended Operating Conditions

Characteristic	Symbol	Min	Typ	Max	Unit
Power Supply Voltage (V_{BATT})		1.8		3.6	Vdc
Operating Temperature Range	T_A	-40	25	85	°C
Logic Input Voltage Low	V_{IL}	0	-	20% V_{BATT}	V
Logic Input Voltage High	V_{IH}	80% V_{BATT}	-	V_{BATT}	V
Logic Output Voltage Low (I_{max} = -1 mA)	V_{OL}	0	-	10% V_{BATT}	V
Logic Output Voltage High (I_{max} = 1 mA)	V_{OH}	90% V_{BATT}	-	V_{BATT}	V
Load capacitance on digital ports	C_L			25	pF
SPI Clock Rate	f_{SPI}	-	-	8.0	MHz
RF Input Power	P_{max}	-	-	0	dBm
Crystal Reference Oscillator Frequency	f_{ref}	32 MHz Only (Some variants may use 30 MHz instead)			

8.3.2 Transceiver Power Consumption

Table 10. Power Supply Current

Characteristic	Conditions	Symbol	Min	Typ	Max	Unit
Supply current in Sleep mode		IDDSL	-	0.1	1	µA
Supply current in Idle mode	RC oscillator enabled	IDDIDLE	-	1.2	-	µA
Supply current in Standby mode	Crystal oscillator enabled	IDDST	-	1.25	1.5	mA
Supply current in Synthesizer mode		IDDFS	-	9	-	mA
Supply current in Receive mode	4.8 kbps 500 kbps	IDDR	-	16 17	-	mA mA
Supply current in Transmit mode with appropriate matching, RF power stable across VDD range, DC current varies with VDD, lower IDDT at lower VDD, typical numbers correspond to mid-range VDD, about 2.7 V	RFOP = +17 dBm, on PA_BOOST RFOP = +13 dBm, on RFIO pin RFOP = +10 dBm, on RFIO pin RFOP = 0 dBm, on RFIO pin RFOP = -1 dBm, on RFIO pin	IDDT	- - - - -	95 45 33 20 16	- - - - -	mA mA mA mA mA

8.3.3 Transceiver Frequency Synthesis

Table 11. Frequency Synthesizer Specification

Characteristic	Conditions	Symbol	Min	Typ	Max	Unit
Synthesizer Frequency Range	Programmable, 32 MHz clock	FR	290 424 862	- - -	340 510 1020	MHz MHz MHz
Crystal oscillator frequency		FXOSC	-	32	-	MHz
Crystal oscillator wake-up time		TS_OSC	-	250	500	µs
Frequency synthesizer wake-up time to PllLock signal	From Standby mode	TS_FS	-	80	150	µs
Frequency synthesizer hop time at most 10 kHz away from the target	200 kHz step 1 MHz step 5 MHz step 7 MHz step 12 MHz step 20 MHz step 25 MHz step	TS_HOP	- - - - - - -	20 20 50 50 80 80 80	- - - - - - -	µs µs µs µs µs µs µs
Frequency synthesizer step	FSTEP = FXOSC/2^{19}	FSTEP	-	61.0	-	Hz
RC Oscillator frequency	After calibration	FRC	-	62.5	-	kHz
Bit rate, FSK	Programmable	BRF	1.2	-	600	kbps
Bit rate, OOK	Programmable	BRO	1.2	-	32.768	kbps
Frequency deviation, FSK	Programmable FDA + BRF/2 =< 500 kHz	FDA	0.6	-	300	kHz

8.3.4 Receiver

All receiver tests are performed with RxBw = 10 kHz (Single Side Bandwidth) as programmed in RegRxBw, receiving a PN15 sequence with a BER of 0.1% (Bit Synchronizer is enabled), unless otherwise specified. The LNA impedance is set to 200 Ohms, by setting bit LnaZin in RegLna to 1. Blocking tests are performed with an unmodulated interferer. The wanted signal power for the Blocking Immunity, ACR, IIP2, IIP3 and AMR tests is set 3 dB above the nominal sensitivity level.

Table 12. Receiver Specification

Characteristic	Conditions	Symbol	Min	Typ	Max	Unit
FSK sensitivity, highest LNA gain	FDA = 5 kHz, BR = 1.2 kb/s FDA = 5 kHz, BR = 4.8 kb/s FDA = 40 kHz, BR = 38.4 kb/s	RFS_F	- - -	-118 -114 -105	- - -	dBm dBm dBm
	FDA = 5 kHz, BR = 1.2 kb/s [1]		-	-120	-	dBm
OOK sensitivity, highest LNA gain	BR = 4.8 kb/s	RFS_O	-	-112	-109	dBm
Co-Channel Rejection		CCR	-13	-10	-	dB
Adjacent Channel Rejection	Offset = +/- 25 kHz Offset = +/- 50 kHz	ACR	- 37	42 42	- -	dB dB
Blocking Immunity	Offset = +/- 1 MHz Offset = +/- 2 MHz Offset = +/- 10 MHz	BI	- - -	66 71 79	- - -	dB dB dB
Blocking Immunity Wanted signal at sensitivity +16dB	Offset = +/- 1 MHz Offset = +/- 2 MHz Offset = +/- 10 MHz		- - -	62 65 73	- - -	dB dB dB
AM Rejection , AM modulated interferer with 100% modulation depth, fm = 1 kHz, square	Offset = +/- 1 MHz Offset = +/- 2 MHz Offset = +/- 10 MHz	AMR	- - -	66 71 79	- - -	dB dB dB
2nd order Input Intercept Point Unwanted tones are 20 MHz above the LO	Lowest LNA gain Highest LNA gain	IIP2	- -	+75 +35	- -	dBm dBm
3rd order Input Intercept point Unwanted tones are 1MHz and 1.995 MHz above the LO	Lowest LNA gain Highest LNA gain	IIP3	- -23	+20 -18	- -	dBm dBm
Single Side channel filter BW	Programmable	BW_SSB	2.6	-	500	kHz
Image rejection in OOK mode	Wanted signal level = -106 dBm	IMR_OOK	27	30	-	dB
Receiver wake-up time, from PLL locked state to *RxReady*	RxBw = 10 kHz, BR = 4.8 kb/s RxBw = 200 kHz, BR = 100 kb/s	TS_RE	- -	1.7 96	- -	ms µs
Receiver wake-up time, from PLL locked state, AGC enabled	RxBw= 10 kHz, BR = 4.8 kb/s RxBw = 200 kHz, BR = 100 kb/s	TS_RE_AGC	-	3.0 163		ms µs
Receiver wake-up time, from PLL lock state, AGC and AFC enabled	RxBw= 10 kHz, BR = 4.8 kb/s RxBw = 200 kHz, BR = 100 kb/s	TS_RE_AGC&AFC		4.8 265		ms µs
FEI sampling time	Receiver is ready	TS_FEI	-	$4.T_{bit}$	-	-
AFC Response Time	Receiver is ready	TS_AFC	-	$4.T_{bit}$	-	-

Table 12. Receiver Specification

Characteristic	Conditions	Symbol	Min	Typ	Max	Unit
RSSI Response Time	Receiver is ready	TS_RSSI	-	2.T_{bit}	-	-
RSSI Dynamic Range	AGC enabled Min Max	DR_RSSI	- -	-115 0	- -	dBm dBm

1 Set SensitivityBoost in RegTestLna to 0x2D to reduce the noise floor in the receiver

8.3.5 Transmitter

Table 13. Transmitter Specidication

Characteristic	Conditions	Symbol	Min	Typ	Max	Unit
RF output power in 50 ohms On RFIO pin	Programmable with 1dB steps Max Min	RF_OP	- -	+13 -18	- -	dBm dBm
Max RF output power, on PA_BOOST pin	With external match to 50 ohms	RF_OPH	-	+17	-	dBm
RF output power stability	From VDD=1.8V to 3.6V	ΔRF_OP	-	+/-0.3	-	dB
Transmitter Phase Noise	50 kHz Offset from carrier 868 / 915 MHz bands 434 / 315 MHz bands	PHN	 - -	 -95 -99	 - -	dBc/Hz
Transmitter adjacent channel power (measured at 25 kHz offset)	BT=0.5 . Measurement conditions as defined by EN 300 220-1 V2.1.1	ACP	-	-	-37	dBm
Transmitter wake up time, to the first rising edge of DCLK	Frequency Synthesizer enabled, *PaRamp* = 10 µs, BR = 4.8 kb/s.	TS_TR	-	120	-	µs

9 Typical Applications Circuit

Figure 7 shows a MKW01 typical applications circuit with and without use of an external power amplifier (PA) (driven by the RF power boost feature). Note a number of circuit features:

1. The two metal flags on the package bottom are independent (unconnected), and as a result, both must be connected to ground.
2. The topology of the external RF matching components is consistent across various frequency bandwidths. Only the component values differ as determined by the desired frequency range.
3. Freescale recommends using a single crystal design (as shown) to minimize systems costs - the circuit must connect transceiver signal DIO5/CLKOUT to the MCU EXTAL input to supply the MCU with a crystal accurate clock source. Also, the MCU initialization must enable the DIO5 pin as the ClkOut function.

Freescale also recommends that the transceiver RESET is driven by an MCU GPIO to provide total hardware control of the transceiver. Figure 7 shows GPIO PTE30 (preferred), but any GPIO can be used.

4. The MKW01Z128 provides in-package connection for the DIO1-DIO0 status to the MCU. External connection of DIO4-DIO2 status to MCU GPIO may be useful or required to implement a wireless node communication algorithm. Enhanced performance can be achieved by routing DIO1 and DIO0 externally to GPIO pins PTC4 and PTC3.
5. The transceiver reference oscillator uses the specified 32 MHz[1] crystal (pins XTA and XTB).
6. A debug port connector will beprovided for programming the MKW01 MCU FLASH and debugging code via the SWD interface.

Two common RF wiring options are shown in Figure 7:

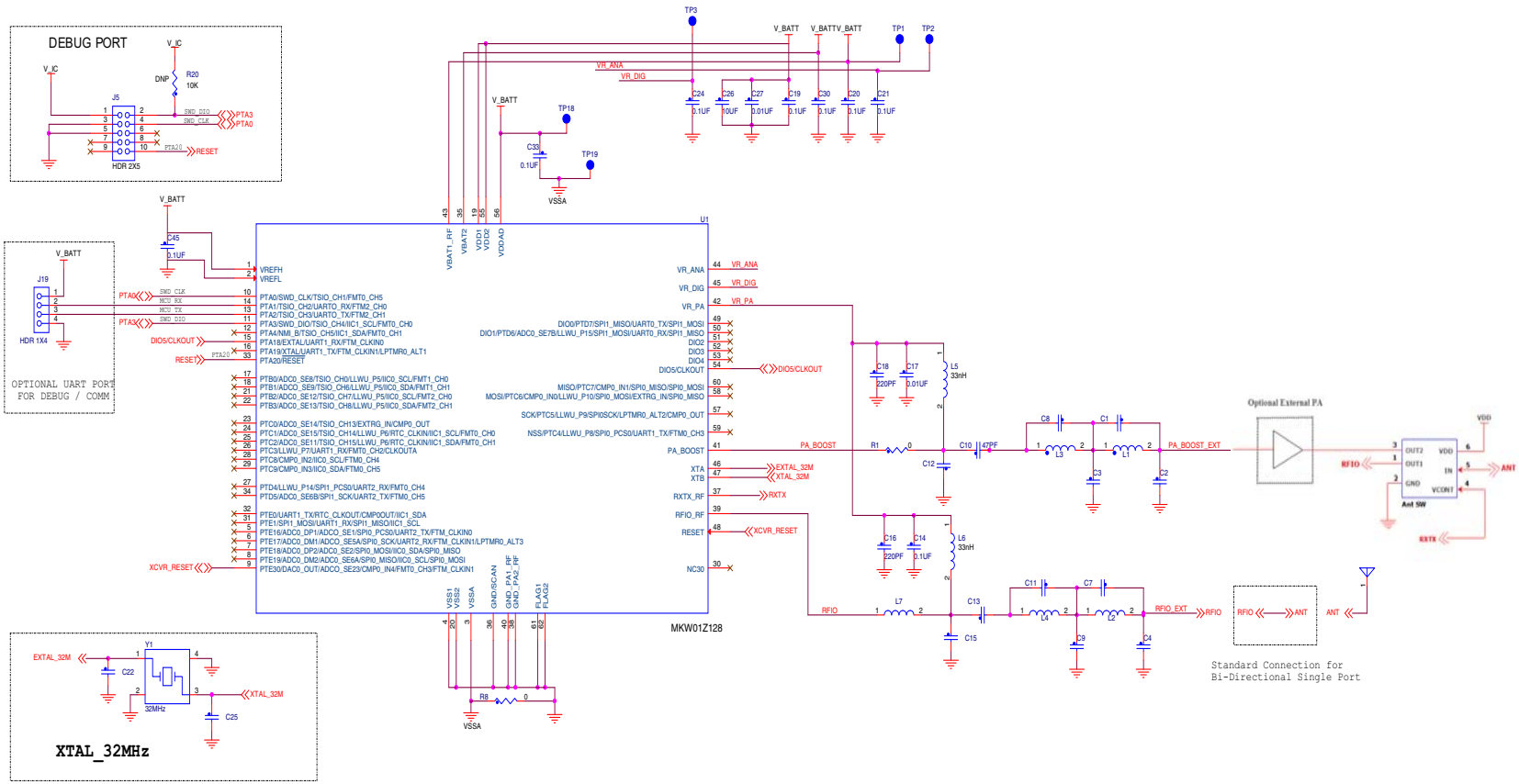
1. Bi-directional single port operation - this mode uses the bi-directional RF port pin of the MKW01 designated as RFIO. The device transmits and receives through this single port.
   - — Typical +13 dBm TX output power
   - — An inductor acts to provide DC power to the transmitter's output amplifier while also acting as an AC signal block.
   - — A circuit topology consisting of inductors and capacitors will provide:
     - – Impedance matching between the RFIO port and the antenna
     - – Low pass filtering for the transmit output path — when fully populated can implement an elliptic-function low pass filter.

NOTE

- The topology for the RF matching network can be used over the various bands of interest with changes in component values
- Not all indicated components are used at all frequencies
- Refer to *MKW01Z128 Sub 1 GHz Low Power Transceiver plus Microcontroller Reference Manual* (MKW01Z128RM.pdf) for additional information

2. Dual port operation with external amplification - this mode uses the RFIO port pin of the MKW01Z128 typically as the RX input and the auxiliary port PA_BOOST as the TX output. An external PA can optionally be inserted into the transmit path and an external antenna switch is also required.
   - — The PA_BOOST has typical +17 dBm output power - this is +4 dBm higher than the RFIO and helps achieve higher power at the PA output.
   - — The PA_BOOST transmit path has a similar filter matching network discussed in the single-port to do low pass filtering and impedance match. The above note about components values also applies.
   - — With separate transmit and receive paths, an antenna switch is required - the RXTX signal or another programmed GPIO can be used to switch paths depending on radio operation.
   - — The receive side matching network can be simplified as no PA DC bias, low pass filtering or harmonic trap is required as is in the transmit and single port networks. When implemented on a new board design, both transmit and receive path component values and even topology should be optimized for best performance on the most important parameters for the application.

1. Or 30 MHz, in some cases.



NOTES:
1) RF components determined by desired frequency range.
2) Recommend that Clkout drive the MCU EXTAL input.
3) Recommend that transceiver RESET be driven from MCU GPIO (PTE30 shown)
4) Transceiver status DIO4- DIO2 may be monitored via external connection to MCU GPIO

Figure 7. MKW01 Application Circuit Options

10 Mechanical Drawings

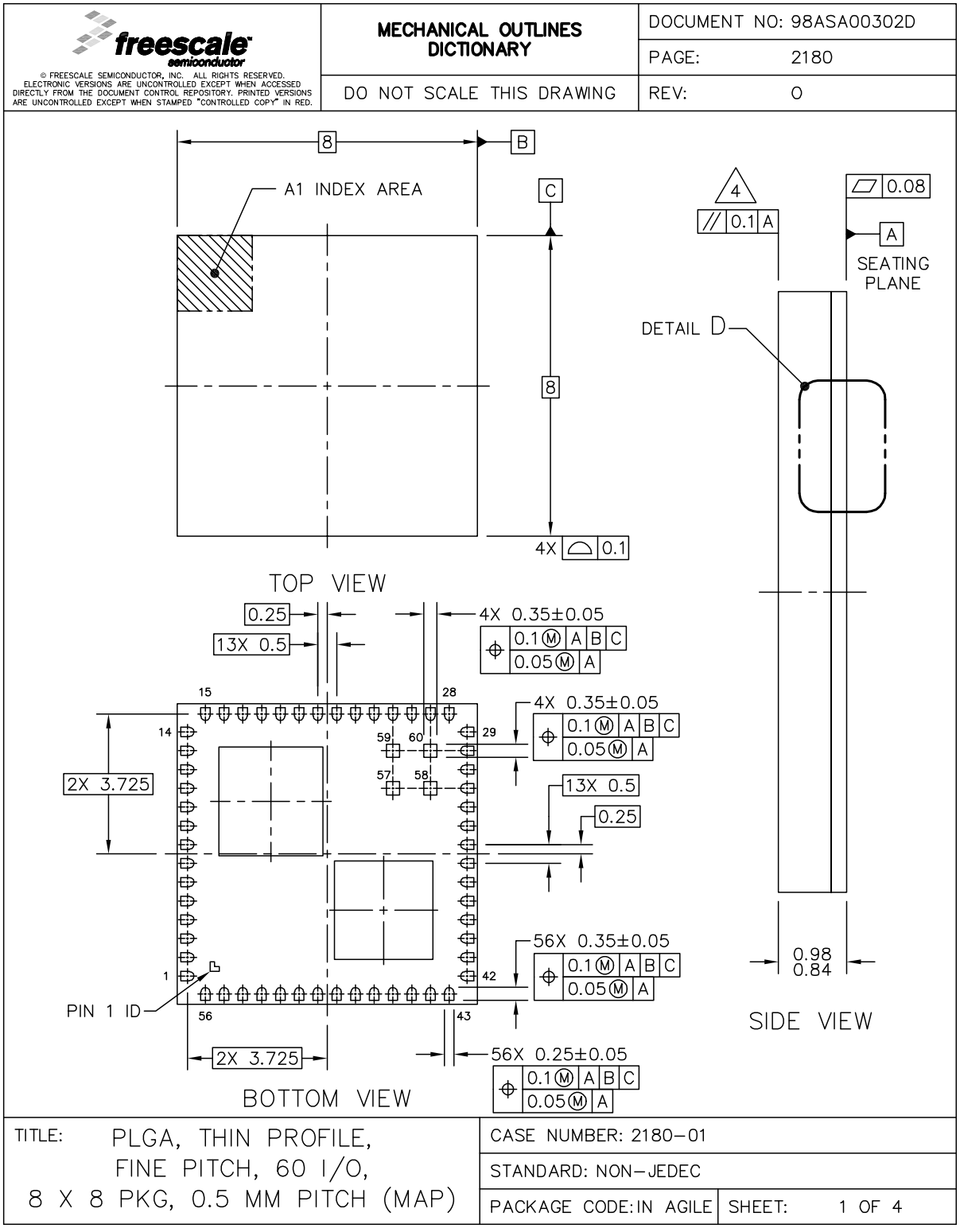


Figure 8. Mechanical Drawing (1 of 2)

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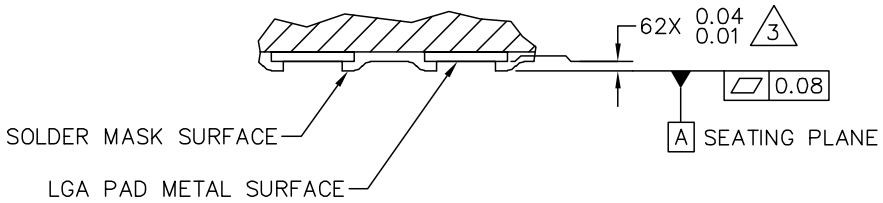
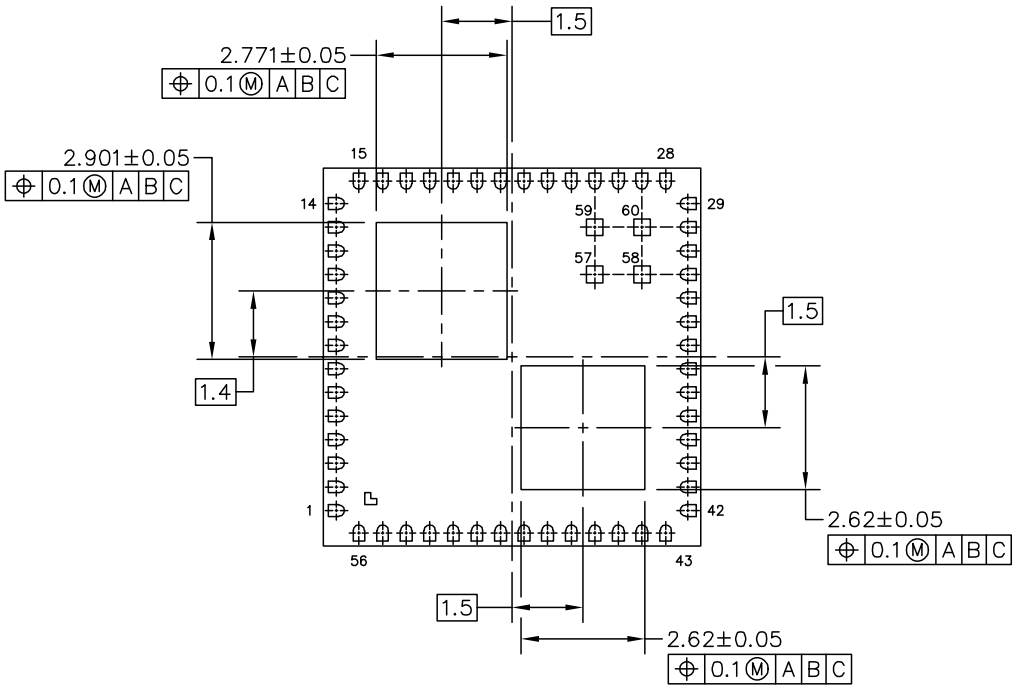


DETAIL D
VIEW ROTATED 90° CW



BOTTOM VIEW

TITLE: PLGA, THIN PROFILE, FINE PITCH, 60 I/O, 8 X 8 PKG, 0.5 MM PITCH (MAP)	CASE NUMBER: 2180-01	
	STANDARD: NON-JEDEC	
	PACKAGE CODE: IN AGILE	SHEET: 2

Figure 9. Mechanical Drawing (2 of 2)

Appendix A MKW01 MCU Section Data Sheet

Freescale Semiconductor
Data Sheet: Technical Data

Document Number MKW01Z128
Rev. 6, 04/2016

MKW01Z128

MKW01 MCU Section Data Sheet

Supports the following: MKW01Z128

Key features

- Operating Characteristics
  - Voltage range: 1.8 to 3.6 V
  - Flash write voltage range: 1.8 to 3.6 V
  - Temperature range (ambient): -40 to 85°C
- Performance
  - Up to 48 MHz ARM® Cortex-M0+ core
- Memories and memory interfaces
  - 128 KB program flash memory
  - 16 KB RAM
- Clocks
  - 32 kHz to 40 kHz or 3 MHz to 32 MHz crystal oscillator
  - Multi-purpose clock source
- System peripherals
  - Nine low-power modes to provide power optimization based on application requirements
  - 4-channel DMA controller, supporting up to 63 request sources
  - COP Software watchdog
  - Low-leakage wakeup unit
  - SWD interface and Micro Trace buffer
  - Bit Manipulation Engine (BME)
- Security and integrity modules
  - 80-bit unique identification (ID) number per chip
- Human-machine interface
  - Low-power hardware touch sensor interface (TSI)
  - General-purpose input/output
- Analog modules
  - 16-bit SAR ADC
  - 12-bit DAC
  - Analog comparator (CMP) containing a 6-bit DAC and programmable reference input
- Timers
  - Six channel Timer/PWM (TPM)
  - Two 2-channel Timer/PWM (TPM)
  - Periodic interrupt timers
  - 16-bit low-power timer (LPTMR)
  - Real-time clock
- Communication interfaces
  - One 16-bit serial peripheral communcation (SPI) module available externally
  - Two I2C modules
  - One low power UART module
  - Two UART modules

Table of Contents

1 General

1.1 Voltage and current operating requirements

Table 1. Voltage and current operating requirements

Symbol	Description	Min.	Max.	Unit	Notes
V_{DD}	Supply voltage	1.8	3.6	V	
V_{DDA}	Analog supply voltage	1.8	3.6	V	
$V_{DD} – V_{DDA}$	V_{DD}-to-V_{DDA} differential voltage	–0.1	0.1	V	
$V_{SS} – V_{SSA}$	V_{SS}-to-V_{SSA} differential voltage	–0.1	0.1	V	
V_{IH}	Input high voltage • 2.7 V ≤ V_{DD} ≤ 3.6 V • 1.7 V ≤ V_{DD} ≤ 2.7 V	 0.7 × V_{DD} 0.75 × V_{DD}	 — —	 V V	
V_{IL}	Input low voltage • 2.7 V ≤ V_{DD} ≤ 3.6 V • 1.7 V ≤ V_{DD} ≤ 2.7 V	 — —	 0.35 × V_{DD} 0.3 × V_{DD}	 V V	
V_{HYS}	Input hysteresis	0.06 × V_{DD}	—	V	
I_{ICIO}	IO pin negative DC injection current — single pin • V_{IN} < V_{SS}-0.3V	-3	—	mA	1
I_{ICcont}	Contiguous pin DC injection current —regional limit, includes sum of negative injection currents of 16 contiguous pins • Negative current injection	-25	—	mA	
V_{ODPU}	Open drain pullup voltage level	V_{DD}	V_{DD}	V	2
V_{RAM}	V_{DD} voltage required to retain RAM	1.2	—	V	

1. All I/O pins are internally clamped to V_{SS} through a ESD protection diode. There is no diode connection to V_{DD}. If V_{IN} greater than V_{IO_MIN} (= V_{SS}-0.3 V) is observed, then there is no need to provide current limiting resistors at the pads. If this limit cannot be observed then a current limiting resistor is required. The negative DC injection current limiting resistor is calculated as R = (V_{IO_MIN} - V_{IN})/|I_{ICIO}|.
2. Open drain outputs must be pulled to V_{DD}.

1.2 LVD and POR operating requirements

Table 2. V_{DD} supply LVD and POR operating requirements

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
V_{POR}	Falling V_{DD} POR detect voltage	0.8	1.1	1.5	V	—

Table continues on the next page...

Table 2. V_{DD} supply LVD and POR operating requirements (continued)

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
V_{LVDH}	Falling low-voltage detect threshold — high range (LVDV = 01)	2.48	2.56	2.64	V	—
	Low-voltage warning thresholds — high range					1
V_{LVW1H}	• Level 1 falling (LVWV = 00)	2.62	2.70	2.78	V	
V_{LVW2H}	• Level 2 falling (LVWV = 01)	2.72	2.80	2.88	V	
V_{LVW3H}	• Level 3 falling (LVWV = 10)	2.82	2.90	2.98	V	
V_{LVW4H}	• Level 4 falling (LVWV = 11)	2.92	3.00	3.08	V	
V_{HYSH}	Low-voltage inhibit reset/recover hysteresis — high range	—	±60	—	mV	—
V_{LVDL}	Falling low-voltage detect threshold — low range (LVDV=00)	1.54	1.60	1.66	V	—
	Low-voltage warning thresholds — low range					1
V_{LVW1L}	• Level 1 falling (LVWV = 00)	1.74	1.80	1.86	V	
V_{LVW2L}	• Level 2 falling (LVWV = 01)	1.84	1.90	1.96	V	
V_{LVW3L}	• Level 3 falling (LVWV = 10)	1.94	2.00	2.06	V	
V_{LVW4L}	• Level 4 falling (LVWV = 11)	2.04	2.10	2.16	V	
V_{HYSL}	Low-voltage inhibit reset/recover hysteresis — low range	—	±40	—	mV	—
V_{BG}	Bandgap voltage reference	0.97	1.00	1.03	V	—
t_{LPO}	Internal low power oscillator period — factory trimmed	900	1000	1100	µs	—

1. Rising thresholds are falling threshold + hysteresis voltage

1.3 Voltage and current operating behaviors

Table 3. Voltage and current operating behaviors

Symbol	Description	Min.	Max.	Unit	Notes
V_{OH}	Output high voltage — Normal drive pad (except RESET_b)				1, 2
	• 2.7 V ≤ V_{DD} ≤ 3.6 V, I_{OH} = -5 mA	V_{DD} – 0.5	—	V	
	• 1.8 V ≤ V_{DD} ≤ 2.7 V, I_{OH} = -2.5 mA	V_{DD} – 0.5	—	V	
V_{OH}	Output high voltage — High drive pad (except RESET_b)				1, 2
	• 2.7 V ≤ V_{DD} ≤ 3.6 V, I_{OH} = -20 mA	V_{DD} – 0.5	—	V	
	• 1.8 V ≤ V_{DD} ≤ 2.7 V, I_{OH} = -10 mA	V_{DD} – 0.5	—	V	
I_{OHT}	Output high current total for all ports	—	100	mA	
V_{OL}	Output low voltage — Normal drive pad				1

Table continues on the next page...

Table 3. Voltage and current operating behaviors (continued)

Symbol	Description	Min.	Max.	Unit	Notes
	• 2.7 V ≤ V_{DD} ≤ 3.6 V, I_{OL} = 5 mA	—	0.5	V	
	• 1.8 V ≤ V_{DD} ≤ 2.7 V, I_{OL} = 2.5 mA	—	0.5	V	
V_{OL}	Output low voltage — High drive pad				1
	• 2.7 V ≤ V_{DD} ≤ 3.6 V, I_{OL} = 20 mA	—	0.5	V	
	• 1.8 V ≤ V_{DD} ≤ 2.7 V, I_{OL} = 10 mA	—	0.5	V	
I_{OLT}	Output low current total for all ports	—	100	mA	
I_{IN}	Input leakage current (per pin) for full temperature range	—	1	µA	3
I_{IN}	Input leakage current (per pin) at 25 °C	—	0.025	µA	3
I_{IN}	Input leakage current (total all pins) for full temperature range	—	65	µA	3
I_{OZ}	Hi-Z (off-state) leakage current (per pin)	—	1	µA	
R_{PU}	Internal pullup and pulldown resistors	20	50	kΩ	4

1. PTB0, PTB1, PTD6, and PTD7 I/O have both high drive and normal drive capability selected by the associated PTx_PCRn[DSE] control bit. All other GPIOs are normal drive only.
2. The reset pin only contains an active pull down device when configured as the RESET signal or as a GPIO. When configured as a GPIO output, it acts as a pseudo open drain output.
3. Measured at V_{DD} = 3.6 V
4. Measured at V_{DD} supply voltage = V_{DD} min and Vinput = V_{SS}

1.4 Power mode transition operating behaviors

All specifications except t_{POR} and VLLSx→RUN recovery times in the following table assume this clock configuration:

- CPU and system clocks = 48 MHz
- Bus and flash clock = 24 MHz
- FEI clock mode

POR and VLLSx→RUN recovery use FEI clock mode at the default CPU and system frequency of 21 MHz, and a bus and flash clock frequency of 10.5 MHz.

Table 4. Power mode transition operating behaviors

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
t_{POR}	After a POR event, amount of time from the point V_{DD} reaches 1.8 V to execution of the first instruction across the operating temperature range of the chip.	—	—	300	µs	1
	• VLLS0 → RUN	—	106	120	µs	

Table continues on the next page...

Table 4. Power mode transition operating behaviors (continued)

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
	• VLLS1 → RUN	—	105	117	µs	
	• VLLS3 → RUN	—	47	54	µs	
	• LLS → RUN	—	4.5	5.0	µs	
	• VLPS → RUN	—	4.5	5.0	µs	
	• STOP → RUN	—	4.5	5.0	µs	

1. Normal boot (FTFA_FOPT[LPBOOT]=11).

1.5 Power consumption operating behaviors

Table 5. Power consumption operating behaviors

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
I_{DDA}	Analog supply current	—	—	See note	mA	1
$I_{DD\_RUNCO\_CM}$	Run mode current in compute operation - 48 MHz core / 24 MHz flash / bus disabled, LPTMR running using 4 MHz internal reference clock, CoreMark benchmark code executing from flash • at 3.0 V	—	6.1	—	mA	2
I_{DD_RUNCO}	Run mode current in compute operation - 48 MHz core / 24 MHz flash / bus clock disabled, code of while(1) loop executing from flash • at 3.0 V	—	3.8	5.9	mA	3
I_{DD_RUN}	Run mode current - 48 MHz core / 24 MHz bus and flash, all peripheral clocks disabled, code of while(1) loop executing from flash • at 3.0 V	—	4.6	6.1	mA	3
I_{DD_RUN}	Run mode current - 48 MHz core / 24 MHz bus and flash, all peripheral clocks enabled, code of while(1) loop executing from flash • at 3.0 V • at 25 °C • at 70 °C • at 125 °C	 — — —	 6.0 6.2 6.3	 6.5 6.8 7.1	 mA mA mA	3, 4

Table continues on the next page...

Table 5. Power consumption operating behaviors (continued)

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
I_{DD_WAIT}	Wait mode current - core disabled / 48 MHz system / 24 MHz bus / flash disabled (flash doze enabled), all peripheral clocks disabled • at 3.0 V	—	2.7	5.7	mA	3
I_{DD_WAIT}	Wait mode current - core disabled / 24 MHz system / 24 MHz bus / flash disabled (flash doze enabled), all peripheral clocks disabled • at 3.0 V	—	2.1	5.5	mA	3
I_{DD_PSTOP2}	Stop mode current with partial stop 2 clocking option - core and system disabled / 10.5 MHz bus • at 3.0 V	—	2.2	4.1	mA	3
$I_{DD\_VLPRCO\_CM}$	Very-low-power run mode current in compute operation - 4 MHz core / 0.8 MHz flash / bus clock disabled, LPTMR running with 4 MHz internal reference clock, CoreMark benchmark code executing from flash • at 3.0 V	—	732	—	µA	5
I_{DD_VLPRCO}	Very-low-power run mode current in compute operation - 4 MHz core / 0.8 MHz flash / bus clock disabled, code of while(1) loop executing from flash • at 3.0 V	—	161	367	µA	6
I_{DD_VLPR}	Very-low-power run mode current - 4 MHz core / 0.8 MHz bus and flash, all peripheral clocks disabled, code of while(1) loop executing from flash • at 3.0 V	—	185	372	µA	6
I_{DD_VLPR}	Very-low-power run mode current - 4 MHz core / 0.8 MHz bus and flash, all peripheral clocks enabled, code of while(1) loop executing from flash • at 3.0 V	—	256	420	µA	4, 6
I_{DD_VLPW}	Very-low-power wait mode current - core disabled / 4 MHz system / 0.8 MHz bus / flash disabled (flash doze enabled), all peripheral clocks disabled • at 3.0 V	—	110	355	µA	6
I_{DD_STOP}	Stop mode current at 3.0 V					
	at 25 °C	—	301	428	µA	
	at 50 °C	—	311	722		
	at 70 °C	—	342	758		
	at 85 °C	—	382	809		
I_{DD_VLPS}	Very-low-power stop mode current at 3.0 V					
	at 25 °C	—	2.3	8.4		

Table continues on the next page...

Table 5. Power consumption operating behaviors (continued)

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
	at 50 °C	—	5.2	18.3	µA	
	at 70 °C	—	10.5	26.1		
	at 85 °C	—	19.3	58.5		
I_{DD_LLS}	Low-leakage stop mode current at 3.0 V				µA	
	at 25 °C	—	1.7	3.3		
	at 50 °C	—	3.2	34.9		
	at 70 °C	—	5.8	38.5		
	at 85 °C	—	11.6	43.8		
I_{DD_VLLS3}	Very-low-leakage stop mode 3 current at 3.0 V				µA	
	at 25 °C	—	1.3	3.0		
	at 50 °C	—	2.3	17.6		
	at 70 °C	—	4.7	19.5		
	at 85 °C	—	8.5	24.1		
I_{DD_VLLS1}	Very-low-leakage stop mode 1 current at 3.0V					
	at 25°C	—	0.7	1.3		
	at 50°C	—	1.2	11.7	µA	
	at 70°C	—	2.2	12.6		
	at 85°C	—	4.8	15.3		
I_{DD_VLLS0}	Very-low-leakage stop mode 0 current (SMC_STOPCTRL[PORPO] = 0) at 3.0 V				nA	
	at 25 °C	—	310	844		
	at 50 °C	—	778	3861		
	at 70 °C	—	1928	13055		
	at 85 °C	—	3906	15457		
I_{DD_VLLS0}	Very-low-leakage stop mode 0 current (SMC_STOPCTRL[PORPO] = 1) at 3.0 V					7
	at 25 °C	—	139	747	nA	
	at 50 °C	—	600	3418		
	at 70 °C	—	1674	11143		
	at 85 °C	—	3554	13683		

1. The analog supply current is the sum of the active or disabled current for each of the analog modules on the device. See each module's specification for its supply current.
2. MCG configured for PEE mode. CoreMark benchmark compiled using IAR 6.40 with optimization level high, optimized for balanced.
3. MCG configured for FEI mode.
4. Incremental current consumption from peripheral activity is not included.
5. MCG configured for BLPI mode. CoreMark benchmark compiled using IAR 6.40 with optimization level high, optimized for balanced.
6. MCG configured for BLPI mode.
7. No brownout

Table 6. Low power mode peripheral adders — typical value

Symbol	Description	Temperature (°C)					Unit
		-40	25	50	70	85	
$I_{IREFSTEN4MHz}$	4 MHz internal reference clock (IRC) adder. Measured by entering STOP or VLPS mode with 4 MHz IRC enabled.	56	56	56	56	56	µA
$I_{IREFSTEN32KHz}$	32 kHz internal reference clock (IRC) adder. Measured by entering STOP mode with the 32 kHz IRC enabled.	52	52	52	52	52	µA
$I_{EREFSTEN4MHz}$	External 4 MHz crystal clock adder. Measured by entering STOP or VLPS mode with the crystal enabled.	250	262	266	268	272	uA
$I_{EREFSTEN32KHz}$	External 32 kHz crystal clock adder by means of the OSC0_CR[ERCLKEN and EREFSTEN] bits. Measured by entering all modes with the crystal enabled.						
	VLLS1	440	490	540	560	570	
	VLLS3	440	490	540	560	570	nA
	LLS	490	490	540	560	570	
	VLPS	510	560	560	560	610	
	STOP	510	560	560	560	610	
I_{CMP}	CMP peripheral adder measured by placing the device in VLLS1 mode with CMP enabled using the 6-bit DAC and a single external input for compare. Includes 6-bit DAC power consumption.	22	22	22	22	22	µA
I_{RTC}	RTC peripheral adder measured by placing the device in VLLS1 mode with external 32 kHz crystal enabled by means of the RTC_CR[OSCE] bit and the RTC ALARM set for 1 minute. Includes ERCLK32K (32 kHz external crystal) power consumption.	432	357	388	475	532	nA
I_{UART}	UART peripheral adder measured by placing the device in STOP or VLPS mode with selected clock source waiting for RX data at 115200 baud rate. Includes selected clock source power consumption.						
	MCGIRCLK (4 MHz internal reference clock)	66	66	66	66	66	µA
	OSCERCLK (4 MHz external crystal)	259	271	275	277	281	
I_{TPM}	TPM peripheral adder measured by placing the device in STOP or VLPS mode with selected clock source configured for output compare generating 100 Hz clock signal. No load is placed on the I/O generating the clock signal. Includes selected clock source and I/O switching currents.						
	MCGIRCLK (4 MHz internal reference clock)	86	86	86	86	86	µA

Table continues on the next page...

Table 6. Low power mode peripheral adders — typical value (continued)

Symbol	Description	Temperature (°C)					Unit
		-40	25	50	70	85	
	OSCERCLK (4 MHz external crystal)	275	288	290	295	300	
I_{BG}	Bandgap adder when BGEN bit is set and device is placed in VLPx, LLS, or VLLSx mode.	45	45	45	45	45	µA
I_{ADC}	ADC peripheral adder combining the measured values at V_{DD} and V_{DDA} by placing the device in STOP or VLPS mode. ADC is configured for low-power mode using the internal clock and continuous conversions.	366	366	366	366	366	µA

1.5.1 Diagram: Typical IDD_RUN operating behavior

The following data was measured under these conditions:

- No GPIOs toggled
- Code execution from flash with cache enabled
- For the ALLOFF curve, all peripheral clocks are disabled except FTFA

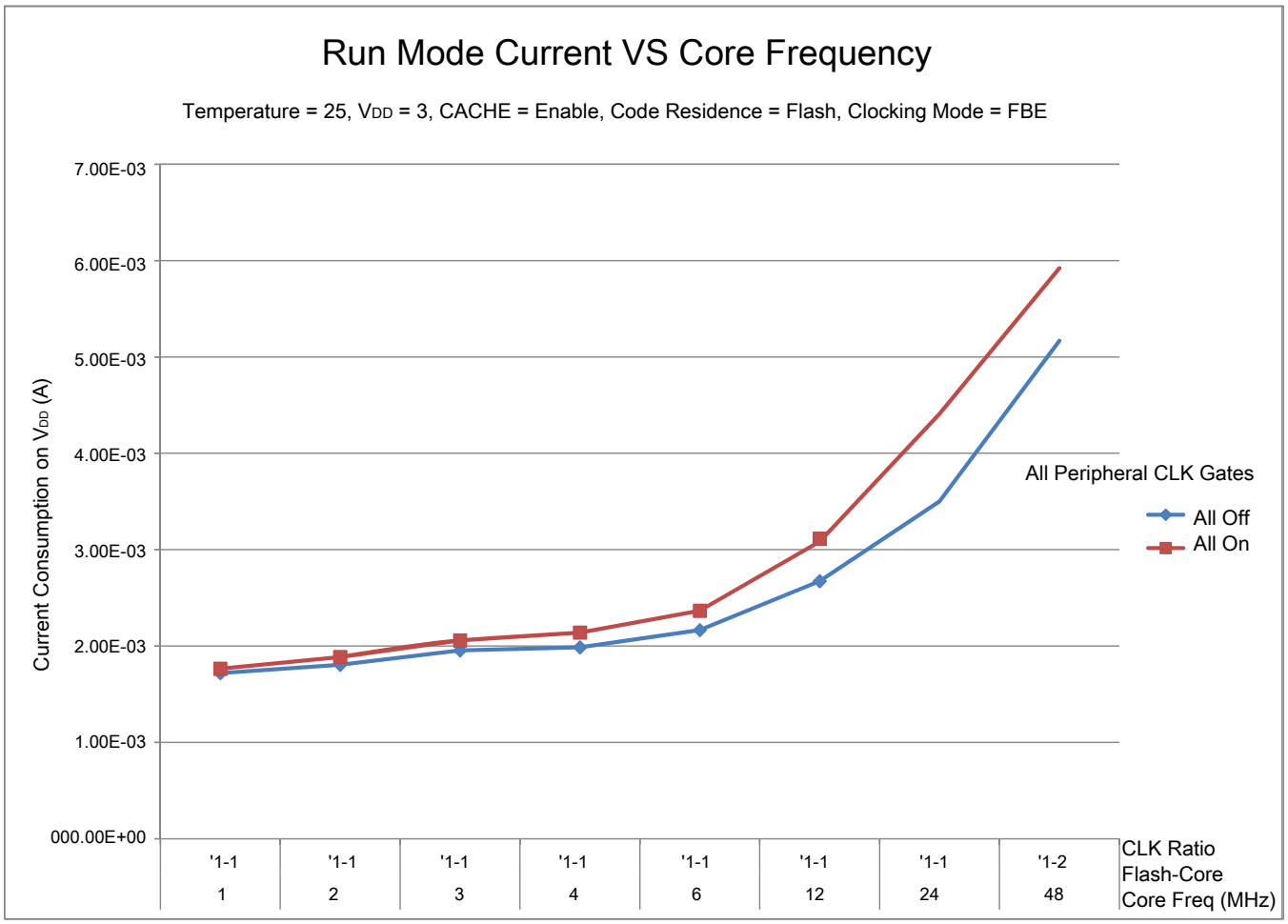


Figure 1. Run mode supply current vs. core frequency

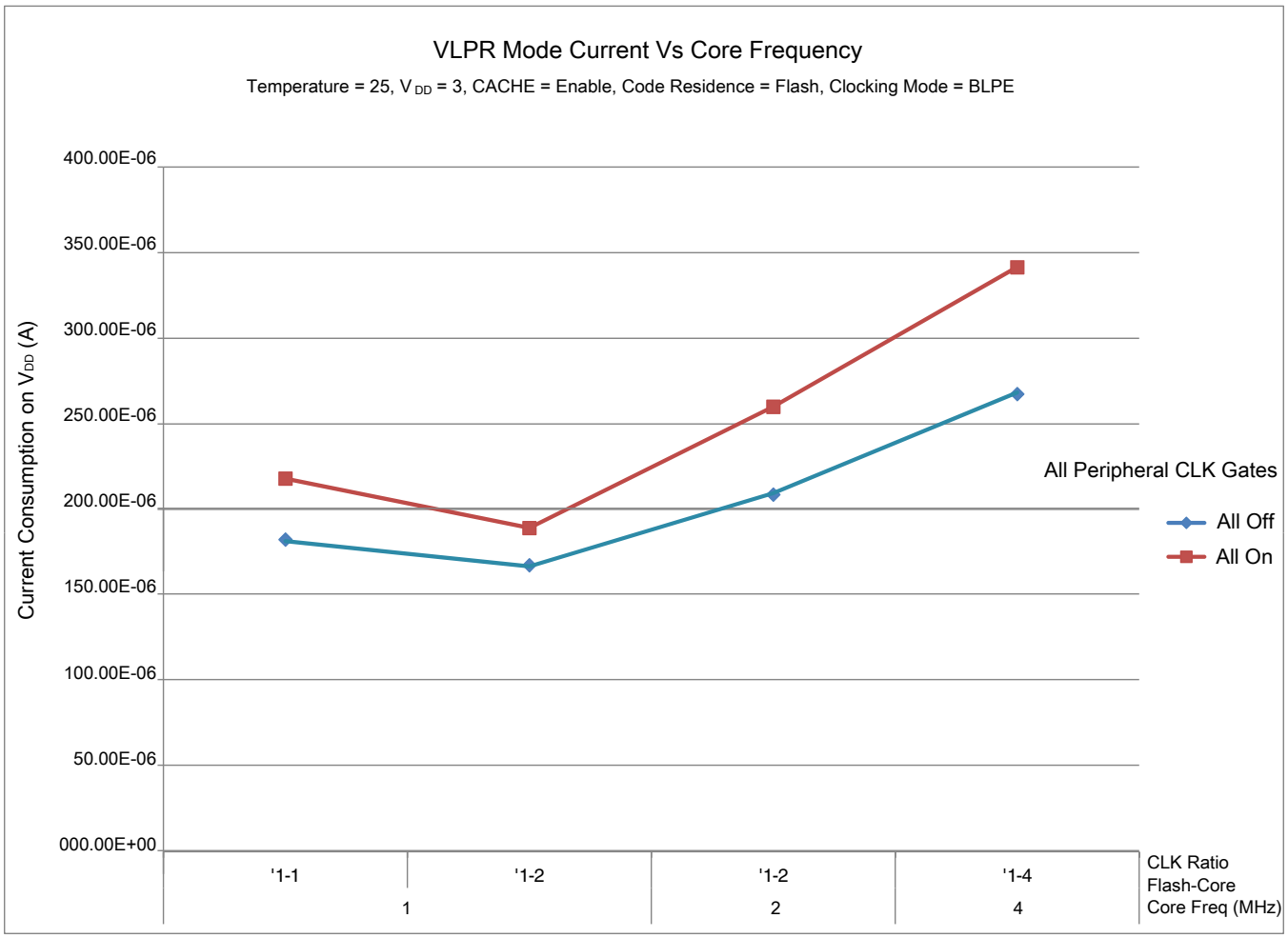


Figure 2. VLPR mode current vs. core frequency

1.6 Designing with radiated emissions in mind

To find application notes that provide guidance on designing your system to minimize interference from radiated emissions:

1. Go to www.freescale.com.
2. Perform a keyword search for “EMC design.”

1.7 Capacitance attributes

Table 7. Capacitance attributes

Symbol	Description	Min.	Max.	Unit
C_{IN}	Input capacitance	—	7	pF

1.8 Switching specifications

1.8.1 Device clock specifications

Table 8. Device clock specifications

Symbol	Description	Min.	Max.	Unit
Normal run mode				
f_{SYS}	System and core clock	—	48	MHz
f_{BUS}	Bus clock	—	24	MHz
f_{FLASH}	Flash clock	—	24	MHz
f_{LPTMR}	LPTMR clock	—	24	MHz
VLPR and VLPS modes[1]				
f_{SYS}	System and core clock	—	4	MHz
f_{BUS}	Bus clock	—	1	MHz
f_{FLASH}	Flash clock	—	1	MHz
f_{LPTMR}	LPTMR clock[2]	—	24	MHz
f_{ERCLK}	External reference clock	—	16	MHz
f_{LPTMR_ERCLK}	LPTMR external reference clock	—	16	MHz
$f_{osc\_hi\_2}$	Oscillator crystal or resonator frequency — high frequency mode (high range) (MCG_C2[RANGE]=1x)	—	16	MHz
f_{TPM}	TPM asynchronous clock	—	8	MHz
f_{UART0}	UART0 asynchronous clock	—	8	MHz

1. The frequency limitations in VLPR and VLPS modes here override any frequency specification listed in the timing specification for any other module. These same frequency limits apply to VLPS, whether VLPS was entered from RUN or from VLPR.
2. The LPTMR can be clocked at this speed in VLPR or VLPS only when the source is an external pin.

1.8.2 General switching specifications

These general-purpose specifications apply to all signals configured for GPIO and UART signals.

Table 9. General switching specifications

Description	Min.	Max.	Unit	Notes
GPIO pin interrupt pulse width (digital glitch filter disabled) — Synchronous path	1.5	—	Bus clock cycles	1
External RESET and NMI pin interrupt pulse width — Asynchronous path	100	—	ns	2
GPIO pin interrupt pulse width — Asynchronous path	16	—	ns	2
Port rise and fall time	—	36	ns	3

1. The greater synchronous and asynchronous timing must be met.
2. This is the shortest pulse that is guaranteed to be recognized.
3. 75 pF load

2 Peripheral operating requirements and behaviors

2.1 Core modules

2.1.1 SWD electricals

Table 10. SWD full voltage range electricals

Symbol	Description	Min.	Max.	Unit
	Operating voltage	1.8	3.6	V
J1	SWD_CLK frequency of operation • Serial wire debug	0	25	MHz
J2	SWD_CLK cycle period	1/J1	—	ns
J3	SWD_CLK clock pulse width • Serial wire debug	20	—	ns
J4	SWD_CLK rise and fall times	—	3	ns
J9	SWD_DIO input data setup time to SWD_CLK rise	10	—	ns
J10	SWD_DIO input data hold time after SWD_CLK rise	0	—	ns
J11	SWD_CLK high to SWD_DIO data valid	—	32	ns
J12	SWD_CLK high to SWD_DIO high-Z	5	—	ns

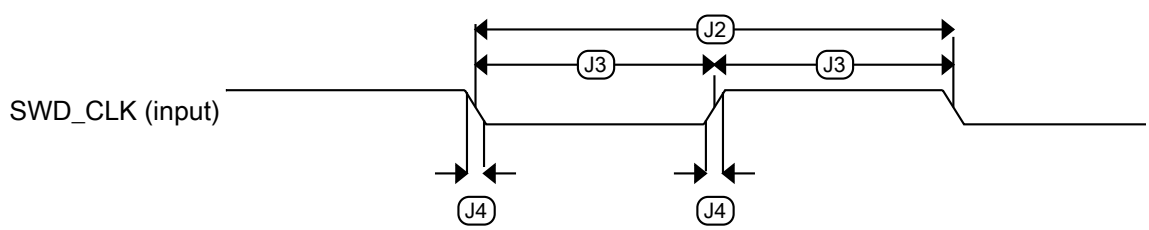


Figure 3. Serial wire clock input timing

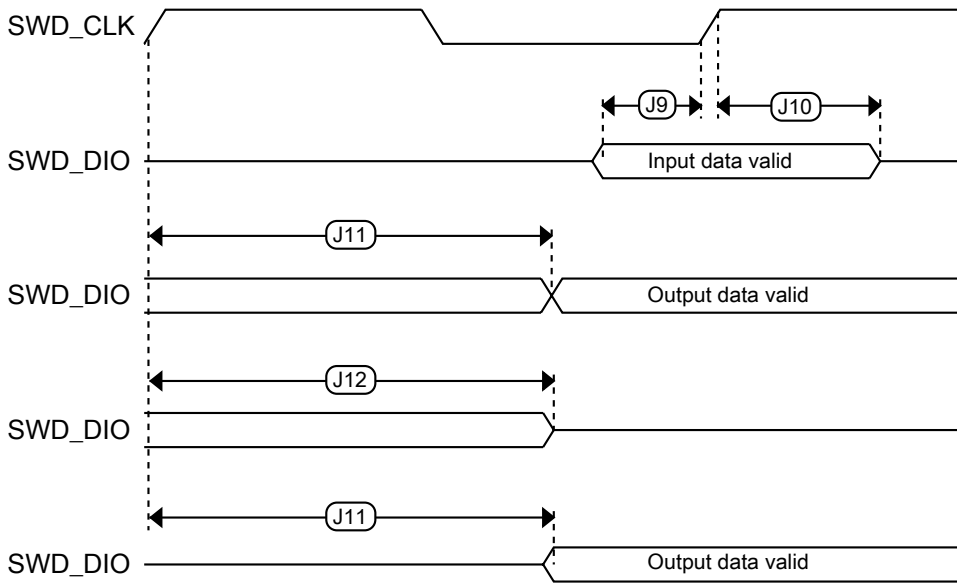


Figure 4. Serial wire data timing

2.2 System modules

There are no specifications necessary for the device's system modules.

2.3 Clock modules

2.3.1 MCG specifications

Table 11. MCG specifications

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
f_{ints_ft}	Internal reference frequency (slow clock) — factory trimmed at nominal V_{DD} and 25 °C	—	32.768	—	kHz	
f_{ints_t}	Internal reference frequency (slow clock) — user trimmed	31.25	—	39.0625	kHz	
$\Delta_{fdco\_res\_t}$	Resolution of trimmed average DCO output frequency at fixed voltage and temperature — using C3[SCTRIM] and C4[SCFTRIM]	—	± 0.3	± 0.6	$\%f_{dco}$	1
Δf_{dco_t}	Total deviation of trimmed average DCO output frequency over voltage and temperature	—	+0.5/-0.7	± 3	$\%f_{dco}$	1, 2

Table continues on the next page...

Table 11. MCG specifications (continued)

Symbol	Description		Min.	Typ.	Max.	Unit	Notes
Δf_{dco_t}	Total deviation of trimmed average DCO output frequency over fixed voltage and temperature range of 0–70 °C		—	± 0.4	± 1.5	$\%f_{dco}$	1, 2
f_{intf_ft}	Internal reference frequency (fast clock) — factory trimmed at nominal V_{DD} and 25 °C		—	4	—	MHz	
Δf_{intf_ft}	Frequency deviation of internal reference clock (fast clock) over temperature and voltage — factory trimmed at nominal V_{DD} and 25 °C		—	+1/-2	± 3	$\%f_{intf\_ft}$	2
f_{intf_t}	Internal reference frequency (fast clock) — user trimmed at nominal V_{DD} and 25 °C		3	—	5	MHz	
f_{loc_low}	Loss of external clock minimum frequency — RANGE = 00		(3/5) x f_{ints_t}	—	—	kHz	
f_{loc_high}	Loss of external clock minimum frequency — RANGE = 01, 10, or 11		(16/5) x f_{ints_t}	—	—	kHz	
FLL							
f_{fll_ref}	FLL reference frequency range		31.25	—	39.0625	kHz	
f_{dco}	DCO output frequency range	Low range (DRS = 00) 640 × f_{fll_ref}	20	20.97	25	MHz	3, 4
		Mid range (DRS = 01) 1280 × f_{fll_ref}	40	41.94	48	MHz	
$f_{dco\_t\_DMX32}$	DCO output frequency	Low range (DRS = 00) 732 × f_{fll_ref}	—	23.99	—	MHz	5, 6
		Mid range (DRS = 01) 1464 × f_{fll_ref}	—	47.97	—	MHz	
J_{cyc_fll}	FLL period jitter • f_{VCO} = 48 MHz		—	180	—	ps	7
$t_{fll\_acquire}$	FLL target frequency acquisition time		—	—	1	ms	8
PLL							
f_{vco}	VCO operating frequency		48.0	—	100	MHz	
I_{pll}	PLL operating current • PLL at 96 MHz ($f_{osc\_hi\_1}$ = 8 MHz, f_{pll_ref} = 2 MHz, VDIV multiplier = 48)		—	1060	—	µA	9
I_{pll}	PLL operating current • PLL at 48 MHz ($f_{osc\_hi\_1}$ = 8 MHz, f_{pll_ref} = 2 MHz, VDIV multiplier = 24)		—	600	—	µA	9
f_{pll_ref}	PLL reference frequency range		2.0	—	4.0	MHz	
J_{cyc_pll}	PLL period jitter (RMS) • f_{vco} = 48 MHz • f_{vco} = 100 MHz		 — —	 120 50	 — —	 ps ps	10
J_{acc_pll}	PLL accumulated jitter over 1µs (RMS) • f_{vco} = 48 MHz • f_{vco} = 100 MHz		 — —	 1350 600	 — —	 ps ps	10

Table continues on the next page...

Table 11. MCG specifications (continued)

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
D_{lock}	Lock entry frequency tolerance	± 1.49	—	± 2.98	%	
D_{unl}	Lock exit frequency tolerance	± 4.47	—	± 5.97	%	
t_{pll_lock}	Lock detector detection time	—	—	$150 \times 10^{-6} + 1075(1/f_{pll\_ref})$	s	11

1. This parameter is measured with the internal reference (slow clock) being used as a reference to the FLL (FEI clock mode).
2. The deviation is relative to the factory trimmed frequency at nominal V_{DD} and 25 °C, f_{ints_ft}.
3. These typical values listed are with the slow internal reference clock (FEI) using factory trim and DMX32 = 0.
4. The resulting system clock frequencies must not exceed their maximum specified values. The DCO frequency deviation (Δf_{dco_t}) over voltage and temperature must be considered.
5. These typical values listed are with the slow internal reference clock (FEI) using factory trim and DMX32 = 1.
6. The resulting clock frequency must not exceed the maximum specified clock frequency of the device.
7. This specification is based on standard deviation (RMS) of period or frequency.
8. This specification applies to any time the FLL reference source or reference divider is changed, trim value is changed, DMX32 bit is changed, DRS bits are changed, or changing from FLL disabled (BLPE, BLPI) to FLL enabled (FEI, FEE, FBE, FBI). If a crystal/resonator is being used as the reference, this specification assumes it is already running.
9. Excludes any oscillator currents that are also consuming power while PLL is in operation.
10. This specification was obtained using a Freescale developed PCB. PLL jitter is dependent on the noise characteristics of each PCB and results will vary.
11. This specification applies to any time the PLL VCO divider or reference divider is changed, or changing from PLL disabled (BLPE, BLPI) to PLL enabled (PBE, PEE). If a crystal/resonator is being used as the reference, this specification assumes it is already running.

2.3.2 Oscillator electrical specifications

2.3.2.1 Oscillator DC electrical specifications

Table 12. Oscillator DC electrical specifications

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
V_{DD}	Supply voltage	1.8	—	3.6	V	
I_{DDOSC}	Supply current — low-power mode (HGO=0)					1
	• 32 kHz	—	500	—	nA	
	• 4 MHz	—	200	—	µA	
	• 8 MHz (RANGE=01)	—	300	—	µA	
	• 16 MHz	—	950	—	µA	
	• 24 MHz	—	1.2	—	mA	
	• 32 MHz	—	1.5	—	mA	
I_{DDOSC}	Supply current — high gain mode (HGO=1)					1
	• 32 kHz	—	25	—	µA	
	• 4 MHz	—	400	—	µA	

Table continues on the next page...

Table 12. Oscillator DC electrical specifications (continued)

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
	• 8 MHz (RANGE=01)	—	500	—	µA	
	• 16 MHz	—	2.5	—	mA	
	• 24 MHz	—	3	—	mA	
	• 32 MHz	—	4	—	mA	
C_x	EXTAL load capacitance	—	—	—		2, 3
C_y	XTAL load capacitance	—	—	—		2, 3
R_F	Feedback resistor — low-frequency, low-power mode (HGO=0)	—	—	—	MΩ	2, 4
	Feedback resistor — low-frequency, high-gain mode (HGO=1)	—	10	—	MΩ	
	Feedback resistor — high-frequency, low-power mode (HGO=0)	—	—	—	MΩ	
	Feedback resistor — high-frequency, high-gain mode (HGO=1)	—	1	—	MΩ	
R_S	Series resistor — low-frequency, low-power mode (HGO=0)	—	—	—	kΩ	
	Series resistor — low-frequency, high-gain mode (HGO=1)	—	200	—	kΩ	
	Series resistor — high-frequency, low-power mode (HGO=0)	—	—	—	kΩ	
	Series resistor — high-frequency, high-gain mode (HGO=1)	—	0	—	kΩ	
V_{pp}[5]	Peak-to-peak amplitude of oscillation (oscillator mode) — low-frequency, low-power mode (HGO=0)	—	0.6	—	V	
	Peak-to-peak amplitude of oscillation (oscillator mode) — low-frequency, high-gain mode (HGO=1)	—	V_{DD}	—	V	
	Peak-to-peak amplitude of oscillation (oscillator mode) — high-frequency, low-power mode (HGO=0)	—	0.6	—	V	
	Peak-to-peak amplitude of oscillation (oscillator mode) — high-frequency, high-gain mode (HGO=1)	—	V_{DD}	—	V	

1. V_{DD}=3.3 V, Temperature =25 °C
2. See crystal or resonator manufacturer's recommendation
3. C_x,C_y can be provided by using the integrated capacitors when the low frequency oscillator (RANGE = 00) is used. For all other cases external capacitors must be used.
4. When low power mode is selected, R_F is integrated and must not be attached externally.
5. The EXTAL and XTAL pins should only be connected to required oscillator components and must not be connected to any other devices.

2.3.2.2 Oscillator frequency specifications

Table 13. Oscillator frequency specifications

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
f_{osc_lo}	Oscillator crystal or resonator frequency — low-frequency mode (MCG_C2[RANGE]=00)	32	—	40	kHz	
$f_{osc\_hi\_1}$	Oscillator crystal or resonator frequency — high-frequency mode (low range) (MCG_C2[RANGE]=01)	3	—	8	MHz	
$f_{osc\_hi\_2}$	Oscillator crystal or resonator frequency — high frequency mode (high range) (MCG_C2[RANGE]=1x)	8	—	32	MHz	
f_{ec_extal}	Input clock frequency (external clock mode)	—	—	48	MHz	1, 2
t_{dc_extal}	Input clock duty cycle (external clock mode)	40	50	60	%	
t_{cst}	Crystal startup time — 32 kHz low-frequency, low-power mode (HGO=0)	—	750	—	ms	3, 4
	Crystal startup time — 32 kHz low-frequency, high-gain mode (HGO=1)	—	250	—	ms	
	Crystal startup time — 8 MHz high-frequency (MCG_C2[RANGE]=01), low-power mode (HGO=0)	—	0.6	—	ms	
	Crystal startup time — 8 MHz high-frequency (MCG_C2[RANGE]=01), high-gain mode (HGO=1)	—	1	—	ms	

1. Other frequency limits may apply when external clock is being used as a reference for the FLL or PLL.
2. When transitioning from FEI or FBI to FBE mode, restrict the frequency of the input clock so that, when it is divided by FRDIV, it remains within the limits of the DCO input clock frequency.
3. Proper PC board layout procedures must be followed to achieve specifications.
4. Crystal startup time is defined as the time between the oscillator being enabled and the OSCINIT bit in the MCG_S register being set.

2.4 Memories and memory interfaces

2.4.1 Flash electrical specifications

This section describes the electrical characteristics of the flash memory module.

2.4.1.1 Flash timing specifications — program and erase

The following specifications represent the amount of time the internal charge pumps are active and do not include command overhead.

Table 14. NVM program/erase timing specifications

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
t_{hvpgm4}	Longword Program high-voltage time	—	7.5	18	µs	—
$t_{hversscr}$	Sector Erase high-voltage time	—	13	113	ms	1
$t_{hversall}$	Erase All high-voltage time	—	52	452	ms	1

1. Maximum time based on expectations at cycling end-of-life.

2.4.1.2 Flash timing specifications — commands

Table 15. Flash command timing specifications

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
$t_{rd1sec1k}$	Read 1s Section execution time (flash sector)	—	—	60	µs	1
t_{pgmchk}	Program Check execution time	—	—	45	µs	1
t_{rdrsrc}	Read Resource execution time	—	—	30	µs	1
t_{pgm4}	Program Longword execution time	—	65	145	µs	—
t_{ersscr}	Erase Flash Sector execution time	—	14	114	ms	2
t_{rd1all}	Read 1s All Blocks execution time	—	—	1.8	ms	1
t_{rdonce}	Read Once execution time	—	—	25	µs	1
$t_{pgmonce}$	Program Once execution time	—	65	—	µs	—
t_{ersall}	Erase All Blocks execution time	—	88	650	ms	2
t_{vfykey}	Verify Backdoor Access Key execution time	—	—	30	µs	1

1. Assumes 25 MHz flash clock frequency.
2. Maximum times for erase parameters based on expectations at cycling end-of-life.

2.4.1.3 Flash high voltage current behaviors

Table 16. Flash high voltage current behaviors

Symbol	Description	Min.	Typ.	Max.	Unit
I_{DD_PGM}	Average current adder during high voltage flash programming operation	—	2.5	6.0	mA
I_{DD_ERS}	Average current adder during high voltage flash erase operation	—	1.5	4.0	mA

2.4.1.4 Reliability specifications

Table 17. NVM reliability specifications

Symbol	Description	Min.	Typ.[1]	Max.	Unit	Notes
Program Flash						
$t_{nvmretp10k}$	Data retention after up to 10 K cycles	5	50	—	years	—
$t_{nvmretp1k}$	Data retention after up to 1 K cycles	20	100	—	years	—
$n_{nvmcycp}$	Cycling endurance	10 K	50 K	—	cycles	2

1. Typical data retention values are based on measured response accelerated at high temperature and derated to a constant 25 °C use profile. Engineering Bulletin EB618 does not apply to this technology. Typical endurance defined in Engineering Bulletin EB619.
2. Cycling endurance represents number of program/erase cycles at –40 °C ≤ T_j ≤ 125 °C.

2.5 Security and integrity modules

There are no specifications necessary for the device's security and integrity modules.

2.6 Analog

2.6.1 ADC electrical specifications

The 16-bit accuracy specifications listed in Table 1 and Table 19 are achievable on the differential pins ADCx_DP0, ADCx_DM0.

All other ADC channels meet the 13-bit differential/12-bit single-ended accuracy specifications.

2.6.1.1 16-bit ADC operating conditions

Table 18. 16-bit ADC operating conditions

Symbol	Description	Conditions	Min.	Typ.[1]	Max.	Unit	Notes
V_{DDA}	Supply voltage	Absolute	1.8	—	3.6	V	
ΔV_{DDA}	Supply voltage	Delta to V_{DD} (V_{DD} – V_{DDA})	-100	0	+100	mV	2
ΔV_{SSA}	Ground voltage	Delta to V_{SS} (V_{SS} – V_{SSA})	-100	0	+100	mV	2
V_{REFH}	ADC reference voltage high		1.13	V_{DDA}	V_{DDA}	V	3
V_{REFL}	ADC reference voltage low		V_{SSA}	V_{SSA}	V_{SSA}	V	3
V_{ADIN}	Input voltage	• 16-bit differential mode • All other modes	VREFL VREFL	— —	31/32 * VREFH VREFH	V	
C_{ADIN}	Input capacitance	• 16-bit mode • 8-bit / 10-bit / 12-bit modes	— —	8 4	10 5	pF	
R_{ADIN}	Input series resistance		—	2	5	kΩ	
R_{AS}	Analog source resistance (external)	13-bit / 12-bit modes f_{ADCK} < 4 MHz	—	—	5	kΩ	4

Table continues on the next page...

Table 18. 16-bit ADC operating conditions (continued)

Symbol	Description	Conditions	Min.	Typ.[1]	Max.	Unit	Notes
f_{ADCK}	ADC conversion clock frequency	≤ 13-bit mode	1.0	—	18.0	MHz	5
f_{ADCK}	ADC conversion clock frequency	16-bit mode	2.0	—	12.0	MHz	5
C_{rate}	ADC conversion rate	≤ 13-bit modes No ADC hardware averaging Continuous conversions enabled, subsequent conversion time	20.000	—	818.330	Ksps	6
C_{rate}	ADC conversion rate	16-bit mode No ADC hardware averaging Continuous conversions enabled, subsequent conversion time	37.037	—	461.467	Ksps	6

1. Typical values assume V_{DDA} = 3.0 V, Temp = 25 °C, f_{ADCK} = 1.0 MHz, unless otherwise stated. Typical values are for reference only, and are not tested in production.
2. DC potential difference.
3. For packages without dedicated VREFH and VREFL pins, V_{REFH} is internally tied to V_{DDA}, and V_{REFL} is internally tied to V_{SSA}.
4. This resistance is external to MCU. To achieve the best results, the analog source resistance must be kept as low as possible. The results in this data sheet were derived from a system that had < 8 Ω analog source resistance. The R_{AS}/C_{AS} time constant should be kept to < 1 ns.
5. To use the maximum ADC conversion clock frequency, CFG2[ADHSC] must be set and CFG1[ADLPC] must be clear.
6. For guidelines and examples of conversion rate calculation, download the ADC calculator tool.

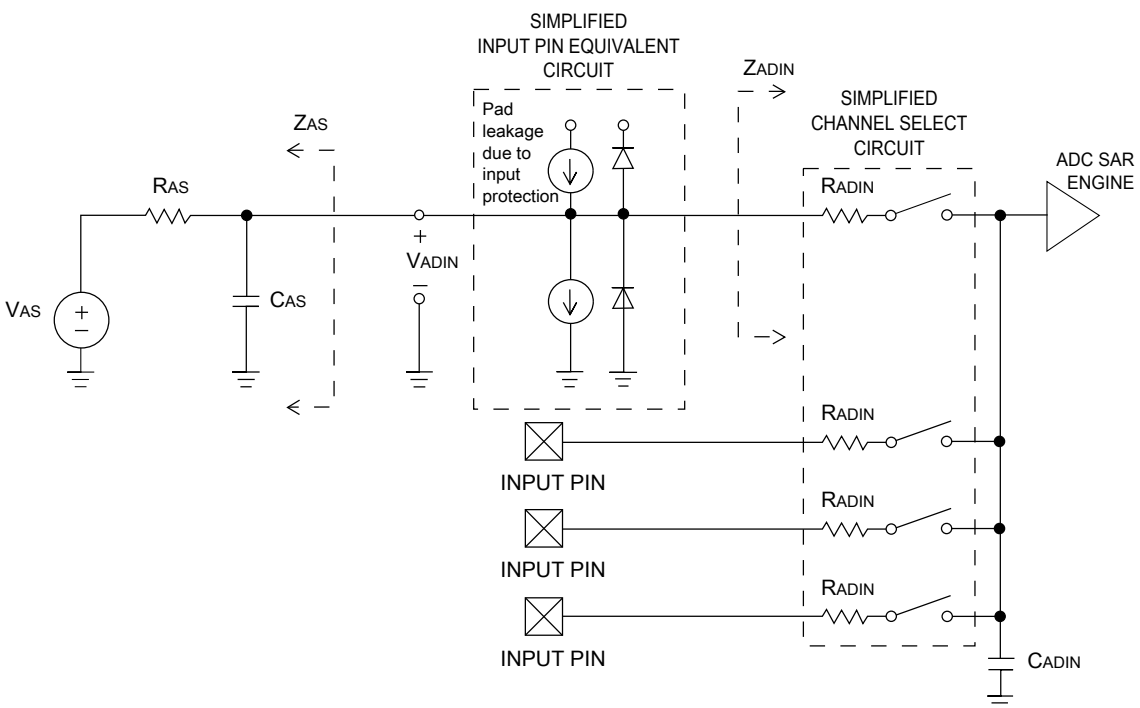


Figure 5. ADC input impedance equivalency diagram

2.6.1.2 16-bit ADC electrical characteristics

Table 19. 16-bit ADC characteristics (V_{REFH} = V_{DDA}, V_{REFL} = V_{SSA})

Symbol	Description	Conditions[1]	Min.	Typ.[2]	Max.	Unit	Notes
I_{DDA_ADC}	Supply current		0.215	—	1.7	mA	3
f_{ADACK}	ADC asynchronous clock source	• ADLPC = 1, ADHSC = 0 • ADLPC = 1, ADHSC = 1 • ADLPC = 0, ADHSC = 0 • ADLPC = 0, ADHSC = 1	1.2 2.4 3.0 4.4	2.4 4.0 5.2 6.2	3.9 6.1 7.3 9.5	MHz MHz MHz MHz	t_{ADACK} = 1/ f_{ADACK}
	Sample Time	See Reference Manual chapter for sample times					
TUE	Total unadjusted error	• 12-bit modes • <12-bit modes	— —	±4 ±1.4	±6.8 ±2.1	LSB[4]	5
DNL	Differential non-linearity	• 12-bit modes • <12-bit modes	— —	±0.7 ±0.2	–1.1 to +1.9 –0.3 to 0.5	LSB[4]	5
INL	Integral non-linearity	• 12-bit modes • <12-bit modes	— —	±1.0 ±0.5	–2.7 to +1.9 –0.7 to +0.5	LSB[4]	5
E_{FS}	Full-scale error	• 12-bit modes • <12-bit modes	— —	–4 –1.4	–5.4 –1.8	LSB[4]	V_{ADIN} = V_{DDA}[5]
E_Q	Quantization error	• 16-bit modes • ≤13-bit modes	— —	–1 to 0 —	— ±0.5	LSB[4]	
ENOB	Effective number of bits	16-bit differential mode • Avg = 32 • Avg = 4 16-bit single-ended mode • Avg = 32 • Avg = 4	 12.8 11.9 12.2 11.4	 14.5 13.8 13.9 13.1	 — — — —	 bits bits bits bits	6
SINAD	Signal-to-noise plus distortion	See ENOB	6.02 × ENOB + 1.76			dB	
THD	Total harmonic distortion	16-bit differential mode • Avg = 32 16-bit single-ended mode • Avg = 32	 — —	 -94 -85	 — —	dB dB	7

Table continues on the next page...

Table 19. 16-bit ADC characteristics ($V_{REFH} = V_{DDA}$, $V_{REFL} = V_{SSA}$) (continued)

Symbol	Description	Conditions[1]	Min.	Typ.[2]	Max.	Unit	Notes
SFDR	Spurious free dynamic range	16-bit differential mode • Avg = 32	82	95	—	dB	7
		16-bit single-ended mode • Avg = 32	78	90	—	dB	
E_{IL}	Input leakage error		$I_{In} \times R_{AS}$			mV	I_{In} = leakage current (refer to the MCU's voltage and current operating ratings)
	Temp sensor slope	Across the full temperature range of the device	1.55	1.62	1.69	mV/°C	8
V_{TEMP25}	Temp sensor voltage	25 °C	706	716	726	mV	8

1. All accuracy numbers assume the ADC is calibrated with $V_{REFH} = V_{DDA}$
2. Typical values assume V_{DDA} = 3.0 V, Temp = 25 °C, f_{ADCK} = 2.0 MHz unless otherwise stated. Typical values are for reference only and are not tested in production.
3. The ADC supply current depends on the ADC conversion clock speed, conversion rate and ADC_CFG1[ADLPC] (low power). For lowest power operation, ADC_CFG1[ADLPC] must be set, the ADC_CFG2[ADHSC] bit must be clear with 1 MHz ADC conversion clock speed.
4. 1 LSB = $(V_{REFH} - V_{REFL})/2^N$
5. ADC conversion clock < 16 MHz, Max hardware averaging (AVGE = %1, AVGS = %11)
6. Input data is 100 Hz sine wave. ADC conversion clock < 12 MHz.
7. Input data is 1 kHz sine wave. ADC conversion clock < 12 MHz.
8. ADC conversion clock < 3 MHz

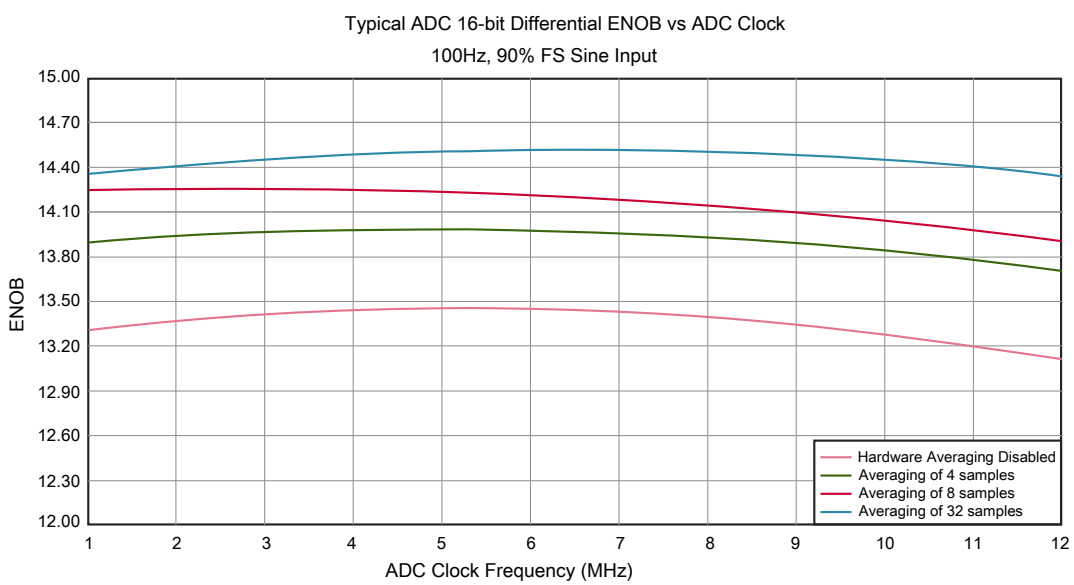


Figure 6. Typical ENOB vs. ADC_CLK for 16-bit differential mode

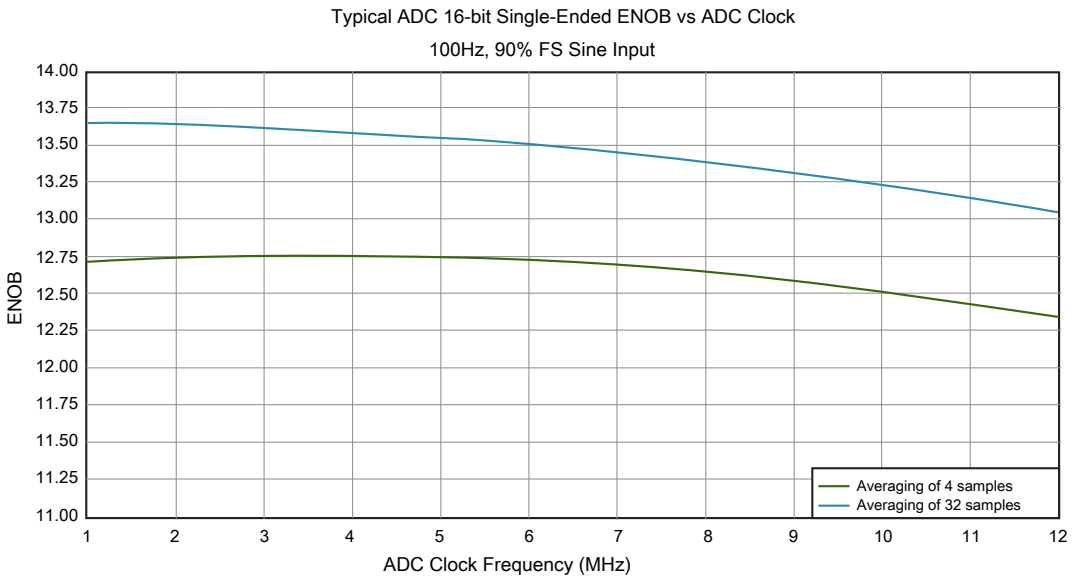


Figure 7. Typical ENOB vs. ADC_CLK for 16-bit single-ended mode

2.6.2 CMP and 6-bit DAC electrical specifications

Table 20. Comparator and 6-bit DAC electrical specifications

Symbol	Description	Min.	Typ.	Max.	Unit
V_{DD}	Supply voltage	1.8	—	3.6	V
I_{DDHS}	Supply current, High-speed mode (EN=1, PMODE=1)	—	—	200	µA
I_{DDLS}	Supply current, low-speed mode (EN=1, PMODE=0)	—	—	20	µA
V_{AIN}	Analog input voltage	V_{SS} – 0.3	—	V_{DD}	V
V_{AIO}	Analog input offset voltage	—	—	20	mV
V_H	Analog comparator hysteresis[1]				
	• CR0[HYSTCTR] = 00	—	5	—	mV
	• CR0[HYSTCTR] = 01	—	10	—	mV
	• CR0[HYSTCTR] = 10	—	20	—	mV
	• CR0[HYSTCTR] = 11	—	30	—	mV
V_{CMPOh}	Output high	V_{DD} – 0.5	—	—	V
V_{CMPOl}	Output low	—	—	0.5	V
t_{DHS}	Propagation delay, high-speed mode (EN=1, PMODE=1)	20	50	200	ns
t_{DLS}	Propagation delay, low-speed mode (EN=1, PMODE=0)	80	250	600	ns
	Analog comparator initialization delay[2]	—	—	40	µs
I_{DAC6b}	6-bit DAC current adder (enabled)	—	7	—	µA
INL	6-bit DAC integral non-linearity	–0.5	—	0.5	LSB[3]
DNL	6-bit DAC differential non-linearity	–0.3	—	0.3	LSB

1. Typical hysteresis is measured with input voltage range limited to 0.6 to V_{DD}–0.6 V.
2. Comparator initialization delay is defined as the time between software writes to change control inputs (Writes to CMP_DACCR[DACEN], CMP_DACCR[VRSEL], CMP_DACCR[VOSEL], CMP_MUXCR[PSEL], and CMP_MUXCR[MSEL]) and the comparator output settling to a stable level.
3. 1 LSB = $V_{reference}$/64

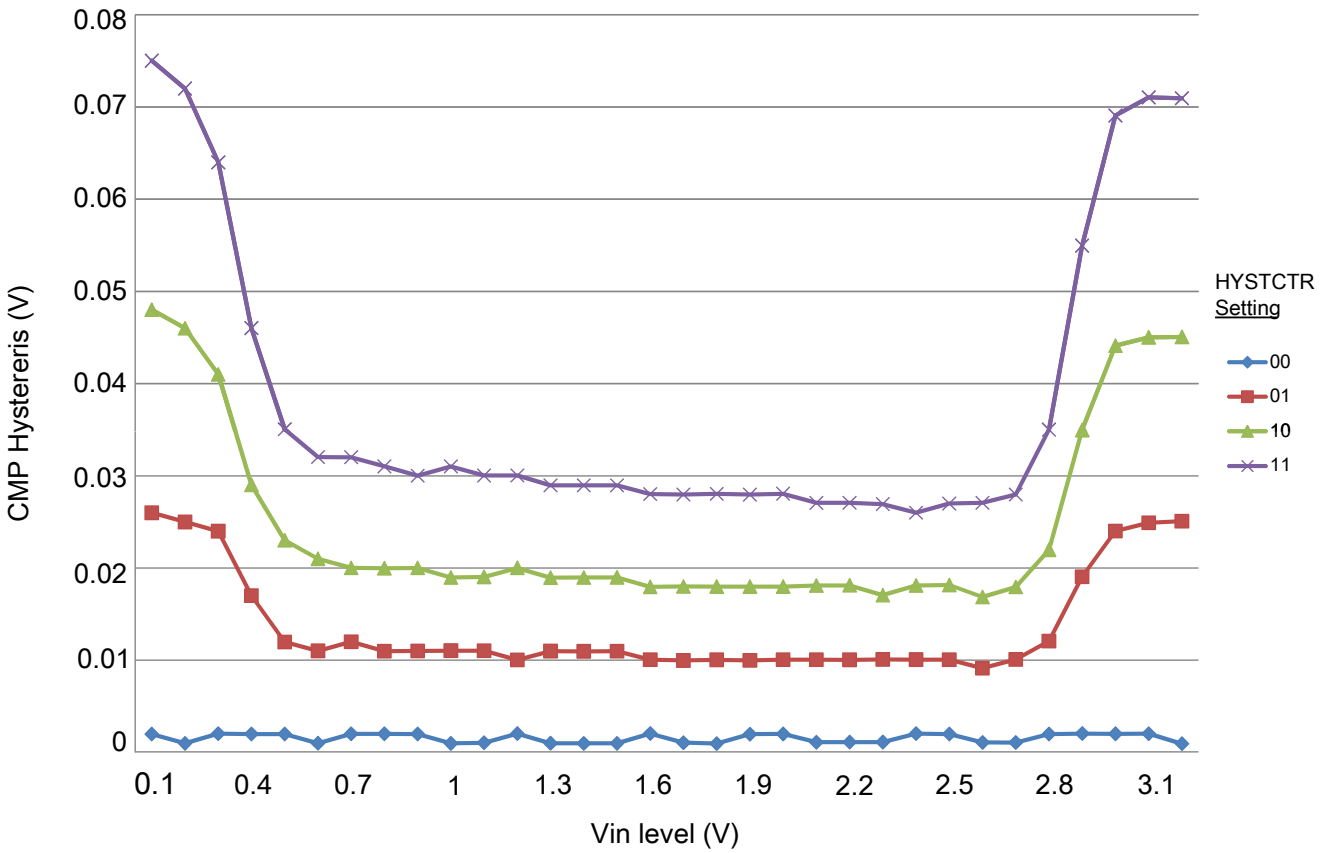


Figure 8. Typical hysteresis vs. Vin level (VDD = 3.3 V, PMODE = 0)

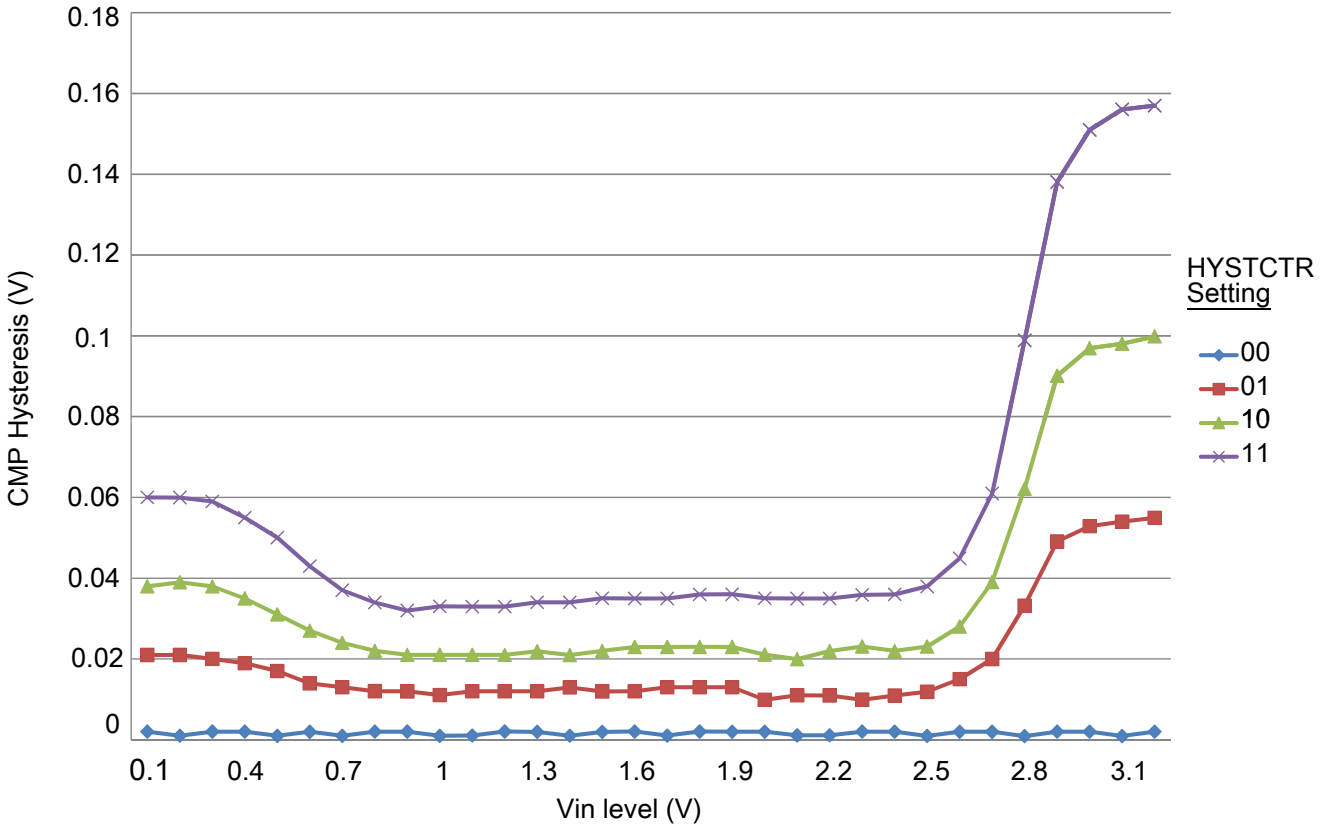


Figure 9. Typical hysteresis vs. Vin level (VDD = 3.3 V, PMODE = 1)

2.6.3 12-bit DAC electrical characteristics

2.6.3.1 12-bit DAC operating requirements

Table 21. 12-bit DAC operating requirements

Symbol	Desciption	Min.	Max.	Unit	Notes
V_{DDA}	Supply voltage	1.8	3.6	V	
V_{DACR}	Reference voltage	1.13	3.6	V	1
C_L	Output load capacitance	—	100	pF	2
I_L	Output load current	—	1	mA	

1. The DAC reference can be selected to be V_{DDA} or VREFH.
2. A small load capacitance (47 pF) can improve the bandwidth performance of the DAC

2.6.3.2 12-bit DAC operating behaviors

Table 22. 12-bit DAC operating behaviors

Symbol	Description	Min.	Typ.	Max.	Unit	Notes
I_{DDA_DACLP}	Supply current — low-power mode	—	—	250	µA	
I_{DDA_DACHP}	Supply current — high-speed mode	—	—	900	µA	
t_{DACLP}	Full-scale settling time (0x080 to 0xF7F) — low-power mode	—	100	200	µs	1
t_{DACHP}	Full-scale settling time (0x080 to 0xF7F) — high-power mode	—	15	30	µs	1
$t_{CCDACLP}$	Code-to-code settling time (0xBF8 to 0xC08) — low-power mode and high-speed mode	—	0.7	1	µs	1
$V_{dacoutl}$	DAC output voltage range low — high-speed mode, no load, DAC set to 0x000	—	—	100	mV	
$V_{dacouth}$	DAC output voltage range high — high-speed mode, no load, DAC set to 0xFFF	V_{DACR} −100	—	V_{DACR}	mV	
INL	Integral non-linearity error — high speed mode	—	—	±8	LSB	2
DNL	Differential non-linearity error — V_{DACR} > 2 V	—	—	±1	LSB	3
DNL	Differential non-linearity error — V_{DACR} = VREF_OUT	—	—	±1	LSB	4
V_{OFFSET}	Offset error	—	±0.4	±0.8	%FSR	5
E_G	Gain error	—	±0.1	±0.6	%FSR	5
PSRR	Power supply rejection ratio, V_{DDA} ≥ 2.4 V	60	—	90	dB	
T_{CO}	Temperature coefficient offset voltage	—	3.7	—	µV/C	6
T_{GE}	Temperature coefficient gain error	—	0.000421	—	%FSR/C	
Rop	Output resistance (load = 3 kΩ)	—	—	250	Ω	
SR	Slew rate -80h→ F7Fh→ 80h				V/µs	
	• High power (SP_{HP})	1.2	1.7	—		
	• Low power (SP_{LP})	0.05	0.12	—		
BW	3dB bandwidth				kHz	
	• High power (SP_{HP})	550	—	—		
	• Low power (SP_{LP})	40	—	—		

1. Settling within ±1 LSB
2. The INL is measured for 0 + 100 mV to V_{DACR} −100 mV
3. The DNL is measured for 0 + 100 mV to V_{DACR} −100 mV
4. The DNL is measured for 0 + 100 mV to V_{DACR} −100 mV with V_{DDA} > 2.4 V
5. Calculated by a best fit curve from V_{SS} + 100 mV to V_{DACR} − 100 mV
6. V_{DDA} = 3.0 V, reference select set for V_{DDA} (DACx_CO:DACRFS = 1), high power mode (DACx_C0:LPEN = 0), DAC set to 0x800, temperature range is across the full range of the device

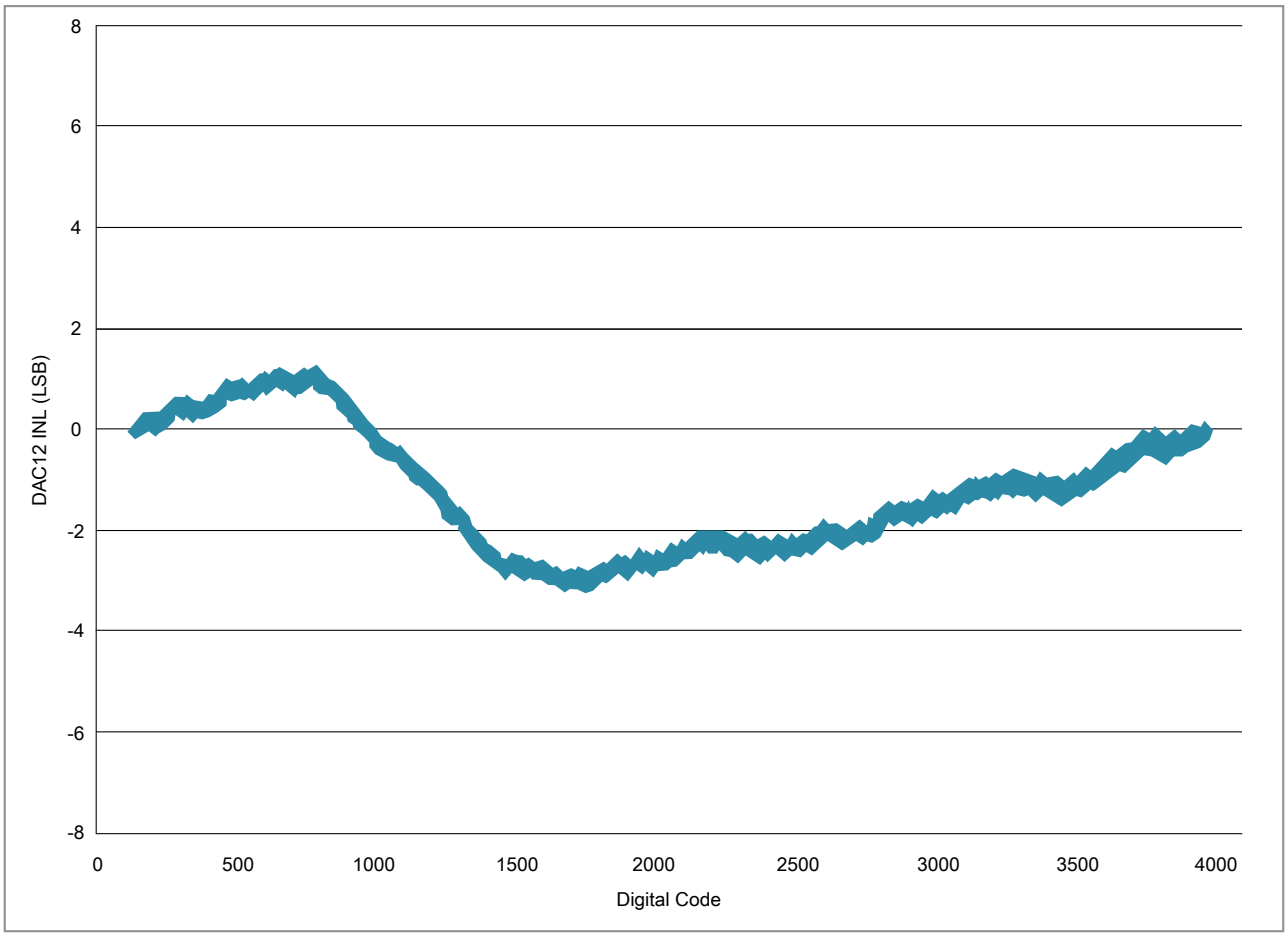


Figure 10. Typical INL error vs. digital code

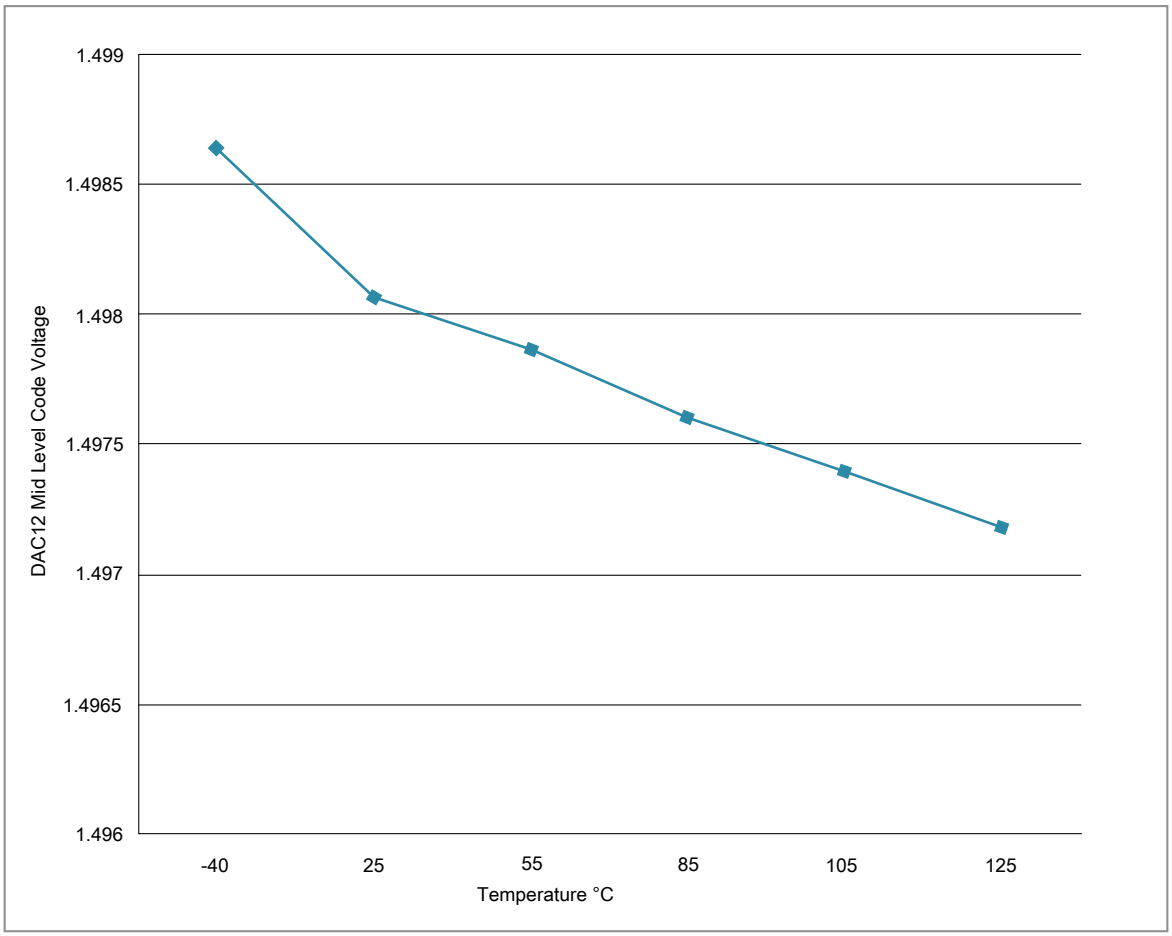


Figure 11. Offset at half scale vs. temperature

2.7 Timers

See General switching specifications.

2.8 Communication interfaces

2.8.1 SPI switching specifications

The Serial Peripheral Interface (SPI) provides a synchronous serial bus with master and slave operations. Many of the transfer attributes are programmable. The following tables provide timing characteristics for classic SPI timing modes. See the SPI chapter of the chip's Reference Manual for information about the modified transfer formats used for communicating with slower peripheral devices.

All timing is shown with respect to 20% V_{DD} and 80% V_{DD} thresholds, unless noted, as well as input signal transitions of 3 ns and a 30 pF maximum load on all SPI pins.

Table 23. SPI master mode timing on slew rate disabled pads

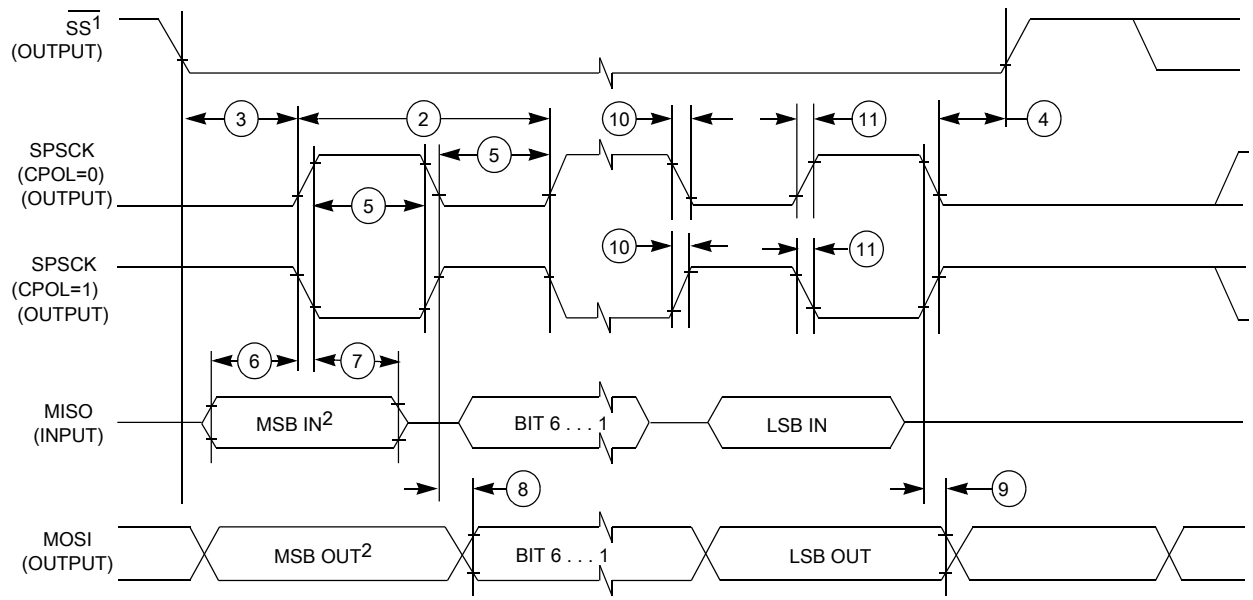
Num.	Symbol	Description	Min.	Max.	Unit	Note
1	f_{op}	Frequency of operation	$f_{periph}/2048$	$f_{periph}/2$	Hz	1
2	t_{SPSCK}	SPSCK period	2 x t_{periph}	2048 x t_{periph}	ns	2
3	t_{Lead}	Enable lead time	1/2	—	t_{SPSCK}	—
4	t_{Lag}	Enable lag time	1/2	—	t_{SPSCK}	—
5	t_{WSPSCK}	Clock (SPSCK) high or low time	t_{periph} - 30	1024 x t_{periph}	ns	—
6	t_{SU}	Data setup time (inputs)	18	—	ns	—
7	t_{HI}	Data hold time (inputs)	0	—	ns	—
8	t_v	Data valid (after SPSCK edge)	—	15	ns	—
9	t_{HO}	Data hold time (outputs)	0	—	ns	—
10	t_{RI}	Rise time input	—	t_{periph} - 25	ns	—
	t_{FI}	Fall time input				
11	t_{RO}	Rise time output	—	25	ns	—
	t_{FO}	Fall time output				

1. For SPI0 f_{periph} is the bus clock (f_{BUS}). For SPI1 f_{periph} is the system clock (f_{SYS}).
2. $t_{periph} = 1/f_{periph}$

Table 24. SPI master mode timing on slew rate enabled pads

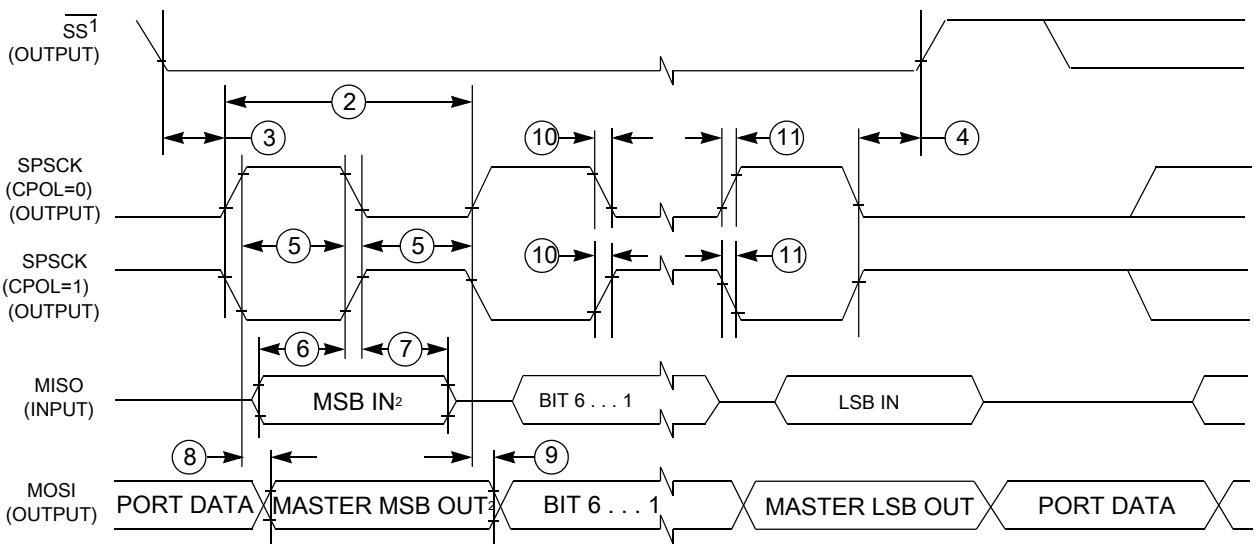
Num.	Symbol	Description	Min.	Max.	Unit	Note
1	f_{op}	Frequency of operation	$f_{periph}/2048$	$f_{periph}/2$	Hz	1
2	t_{SPSCK}	SPSCK period	2 x t_{periph}	2048 x t_{periph}	ns	2
3	t_{Lead}	Enable lead time	1/2	—	t_{SPSCK}	—
4	t_{Lag}	Enable lag time	1/2	—	t_{SPSCK}	—
5	t_{WSPSCK}	Clock (SPSCK) high or low time	t_{periph} - 30	1024 x t_{periph}	ns	—
6	t_{SU}	Data setup time (inputs)	96	—	ns	—
7	t_{HI}	Data hold time (inputs)	0	—	ns	—
8	t_v	Data valid (after SPSCK edge)	—	52	ns	—
9	t_{HO}	Data hold time (outputs)	0	—	ns	—
10	t_{RI}	Rise time input	—	t_{periph} - 25	ns	—
	t_{FI}	Fall time input				
11	t_{RO}	Rise time output	—	36	ns	—
	t_{FO}	Fall time output				

1. For SPI0 f_{periph} is the bus clock (f_{BUS}). For SPI1 f_{periph} is the system clock (f_{SYS}).
2. $t_{periph} = 1/f_{periph}$



1. If configured as an output.
2. LSBF = 0. For LSBF = 1, bit order is LSB, bit 1, ..., bit 6, MSB.

Figure 12. SPI master mode timing (CPHA = 0)



1.If configured as output
2. LSBF = 0. For LSBF = 1, bit order is LSB, bit 1, ..., bit 6, MSB.

Figure 13. SPI master mode timing (CPHA = 1)

Table 25. SPI slave mode timing on slew rate disabled pads

Num.	Symbol	Description	Min.	Max.	Unit	Note
1	f_{op}	Frequency of operation	0	$f_{periph}/4$	Hz	1
2	t_{SPSCK}	SPSCK period	4 x t_{periph}	—	ns	2
3	t_{Lead}	Enable lead time	1	—	t_{periph}	—
4	t_{Lag}	Enable lag time	1	—	t_{periph}	—
5	t_{WSPSCK}	Clock (SPSCK) high or low time	t_{periph} - 30	—	ns	—

Table continues on the next page...

Table 25. SPI slave mode timing on slew rate disabled pads (continued)

Num.	Symbol	Description	Min.	Max.	Unit	Note
6	t_{SU}	Data setup time (inputs)	2.5	—	ns	—
7	t_{HI}	Data hold time (inputs)	3.5	—	ns	—
8	t_a	Slave access time	—	t_{periph}	ns	3
9	t_{dis}	Slave MISO disable time	—	t_{periph}	ns	4
10	t_v	Data valid (after SPSCK edge)	—	31	ns	—
11	t_{HO}	Data hold time (outputs)	0	—	ns	—
12	t_{RI}	Rise time input	—	t_{periph} - 25	ns	—
	t_{FI}	Fall time input				
13	t_{RO}	Rise time output	—	25	ns	—
	t_{FO}	Fall time output				

1. For SPI0 f_{periph} is the bus clock (f_{BUS}). For SPI1 f_{periph} is the system clock (f_{SYS}).
2. $t_{periph} = 1/f_{periph}$
3. Time to data active from high-impedance state
4. Hold time to high-impedance state

Table 26. SPI slave mode timing on slew rate enabled pads

Num.	Symbol	Description	Min.	Max.	Unit	Note
1	f_{op}	Frequency of operation	0	$f_{periph}/4$	Hz	1
2	t_{SPSCK}	SPSCK period	4 x t_{periph}	—	ns	2
3	t_{Lead}	Enable lead time	1	—	t_{periph}	—
4	t_{Lag}	Enable lag time	1	—	t_{periph}	—
5	t_{WSPSCK}	Clock (SPSCK) high or low time	t_{periph} - 30	—	ns	—
6	t_{SU}	Data setup time (inputs)	2	—	ns	—
7	t_{HI}	Data hold time (inputs)	7	—	ns	—
8	t_a	Slave access time	—	t_{periph}	ns	3
9	t_{dis}	Slave MISO disable time	—	t_{periph}	ns	4
10	t_v	Data valid (after SPSCK edge)	—	122	ns	—
11	t_{HO}	Data hold time (outputs)	0	—	ns	—
12	t_{RI}	Rise time input	—	t_{periph} - 25	ns	—
	t_{FI}	Fall time input				
13	t_{RO}	Rise time output	—	36	ns	—
	t_{FO}	Fall time output				

1. For SPI0 f_{periph} is the bus clock (f_{BUS}). For SPI1 f_{periph} is the system clock (f_{SYS}).
2. $t_{periph} = 1/f_{periph}$
3. Time to data active from high-impedance state
4. Hold time to high-impedance state

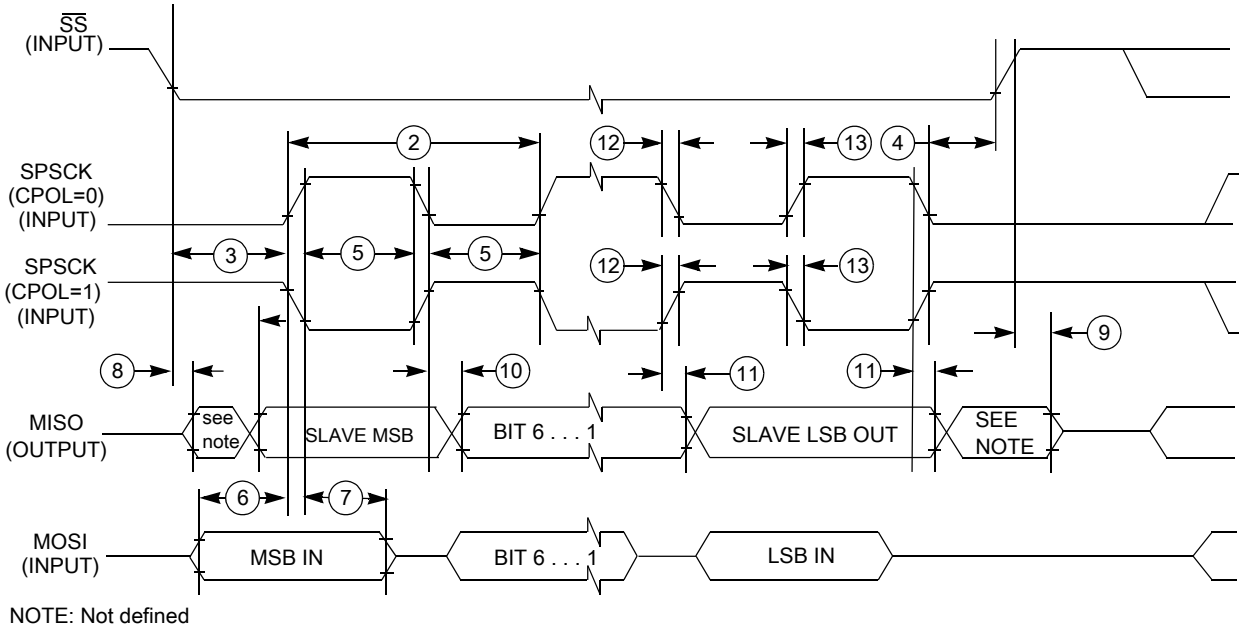


Figure 14. SPI slave mode timing (CPHA = 0)

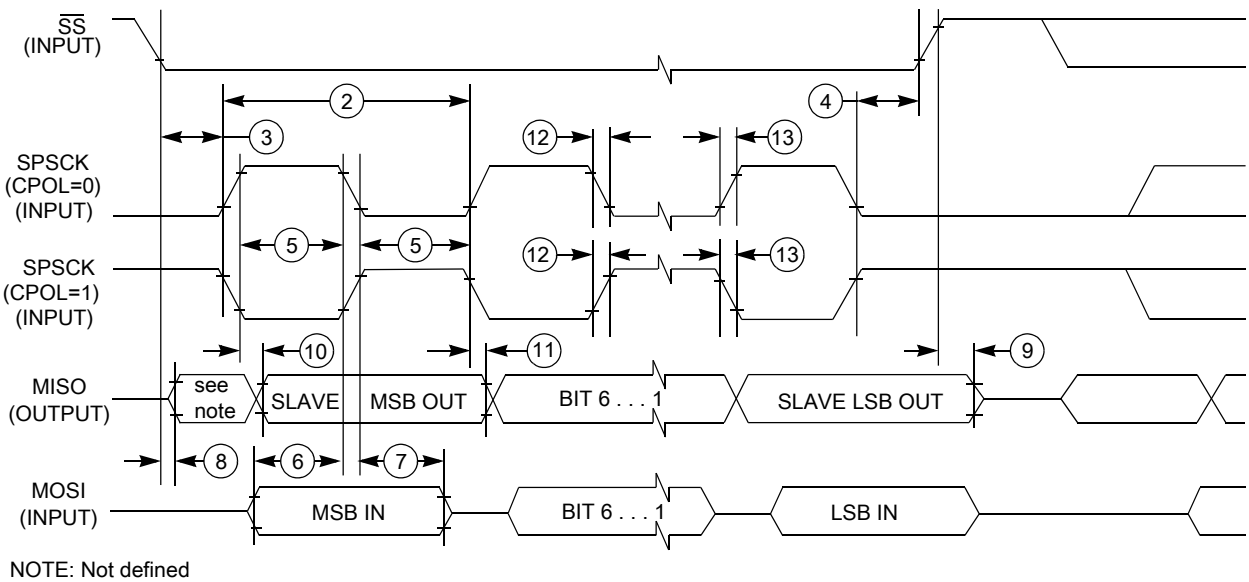


Figure 15. SPI slave mode timing (CPHA = 1)

2.8.2 Inter-Integrated Circuit Interface (I^2C) timing

Table 27. I^2C timing

Characteristic	Symbol	Standard Mode		Fast Mode		Unit
		Minimum	Maximum	Minimum	Maximum	
SCL Clock Frequency	f_{SCL}	0	100	0	400	kHz

Table continues on the next page...

Table 27. I²C timing (continued)

Characteristic	Symbol	Standard Mode		Fast Mode		Unit
		Minimum	Maximum	Minimum	Maximum	
Hold time (repeated) START condition. After this period, the first clock pulse is generated.	t_{HD}; STA	4	—	0.6	—	µs
LOW period of the SCL clock	t_{LOW}	4.7	—	1.3	—	µs
HIGH period of the SCL clock	t_{HIGH}	4	—	0.6	—	µs
Set-up time for a repeated START condition	t_{SU}; STA	4.7	—	0.6	—	µs
Data hold time for I²C bus devices	t_{HD}; DAT	0[1]	3.45[2]	0[3]	0.9[1]	µs
Data set-up time	t_{SU}; DAT	250[4]	—	100[2, 5]	—	ns
Rise time of SDA and SCL signals	t_r	—	1000	20 +0.1C_b[6]	300	ns
Fall time of SDA and SCL signals	t_f	—	300	20 +0.1C_b[5]	300	ns
Set-up time for STOP condition	t_{SU}; STO	4	—	0.6	—	µs
Bus free time between STOP and START condition	t_{BUF}	4.7	—	1.3	—	µs
Pulse width of spikes that must be suppressed by the input filter	t_{SP}	N/A	N/A	0	50	ns

1. The master mode I²C deasserts ACK of an address byte simultaneously with the falling edge of SCL. If no slaves acknowledge this address byte, then a negative hold time can result, depending on the edge rates of the SDA and SCL lines.
2. The maximum tHD; DAT must be met only if the device does not stretch the LOW period (tLOW) of the SCL signal.
3. Input signal Slew = 10 ns and Output Load = 50 pF
4. Set-up time in slave-transmitter mode is 1 IPBus clock period, if the TX FIFO is empty.
5. A Fast mode I²C bus device can be used in a Standard mode I2C bus system, but the requirement $t_{SU;\ DAT} \geq 250$ ns must then be met. This is automatically the case if the device does not stretch the LOW period of the SCL signal. If such a device does stretch the LOW period of the SCL signal, then it must output the next data bit to the SDA line $t_{rmax} + t_{SU;\ DAT} = 1000 + 250 = 1250$ ns (according to the Standard mode I²C bus specification) before the SCL line is released.
6. C_b = total capacitance of the one bus line in pF.

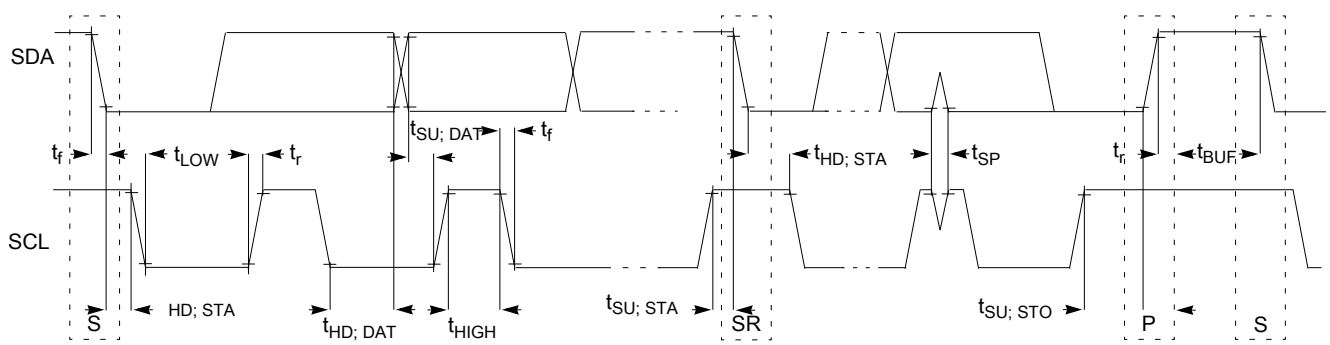


Figure 16. Timing definition for fast and standard mode devices on the I²C bus

2.8.3 UART

See General switching specifications.

2.9 Human-machine interfaces (HMI)

2.9.1 TSI electrical specifications

Table 28. TSI electrical specifications

Symbol	Description	Min.	Typ.	Max.	Unit
TSI_RUNF	Fixed power consumption in run mode	—	100	—	µA
TSI_RUNV	Variable power consumption in run mode (depends on oscillator's current selection)	1.0	—	128	µA
TSI_EN	Power consumption in enable mode	—	100	—	µA
TSI_DIS	Power consumption in disable mode	—	1.2	—	µA
TSI_TEN	TSI analog enable time	—	66	—	µs
TSI_CREF	TSI reference capacitor	—	1.0	—	pF
TSI_DVOLT	Voltage variation of VP & VM around nominal values	0.19	—	1.03	V

3 Revision History

The following table provides a revision history for this document.

Table 29. Revision History

Rev. No.	Date	Substantial Changes
6	April 2016	• Updated RF Transceiver features list in topic 2.2. • Made text changes in the 'Supply current in Transmit mode' characteristic in Table 10. Power Supply Current. • Updated Typical values of 'Blocking Immunity', 'AM Rejection , AM modulated' characteristics in Table 12. Receiver Specification. • Updated content of RF wiring options in topic "Typical Applications Circuit" and also updated the circuit diagram to be visually clear. • Corrected description of $I_{EREFSTEN32KHz}$ in Table 6. Low power mode peripheral adders — typical value.

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